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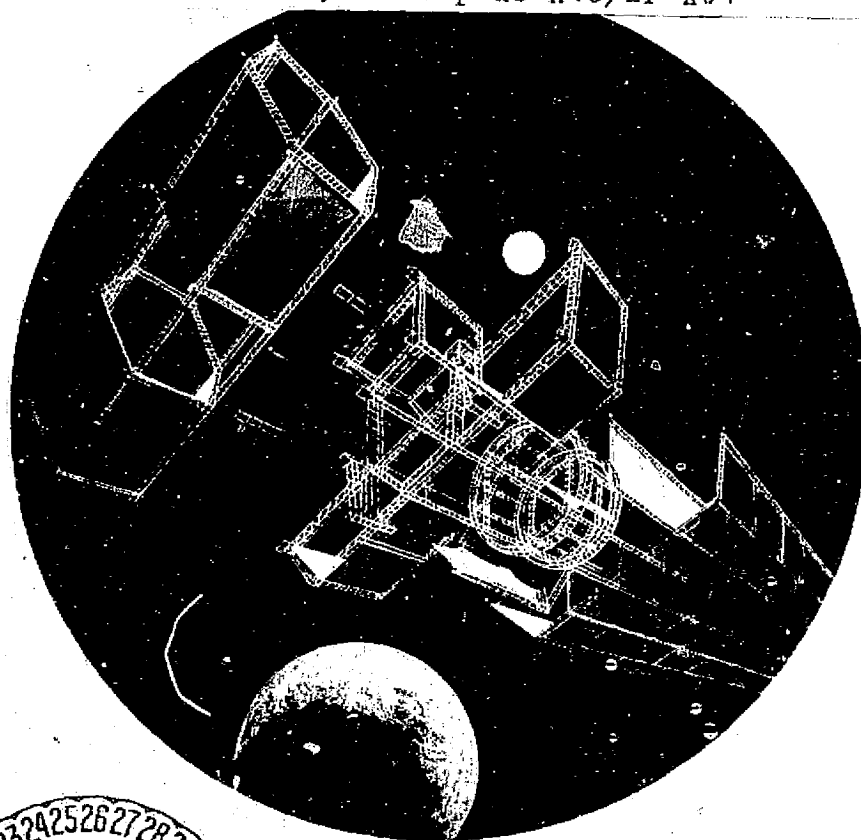
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SD 78-AP-0075

**SATELLITE POWER SYSTEM (SPS)
CONCEPT DEFINITION STUDY
(EXHIBIT C)
FIRST QUARTERLY REVIEW**

MARSHALL SPACE FLIGHT CENTER

JUNE 21-22, 1978



Rockwell International
Space Division

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First Quarterly Review

**SATELLITE POWER SYSTEMS (SPS)
CONCEPT DEFINITION STUDY
(EXHIBIT C)**

June 21-22, 1978

Prepared for:

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER**

**MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812**

**G.M. Hanley
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AGENDA

SUMMARY

G.M. HANLEY

SYSTEM ANALYSIS

- OVERVIEW—
A.A. NUSSBERGER
- MICROWAVE
TRANSMISSION—
G. O'CLOCK

SPECIAL EMPHASIS STUDIES

W. V. MC RAE

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TRANSPORTATION

R. P. BERGERON

EXPERIMENTAL/ VERIFICATION PLAN

- OVERVIEW—
W. R. RHOTE
- SOLAR CELLS—
R. P. RUTH

COST AND PROGRAMMATICS

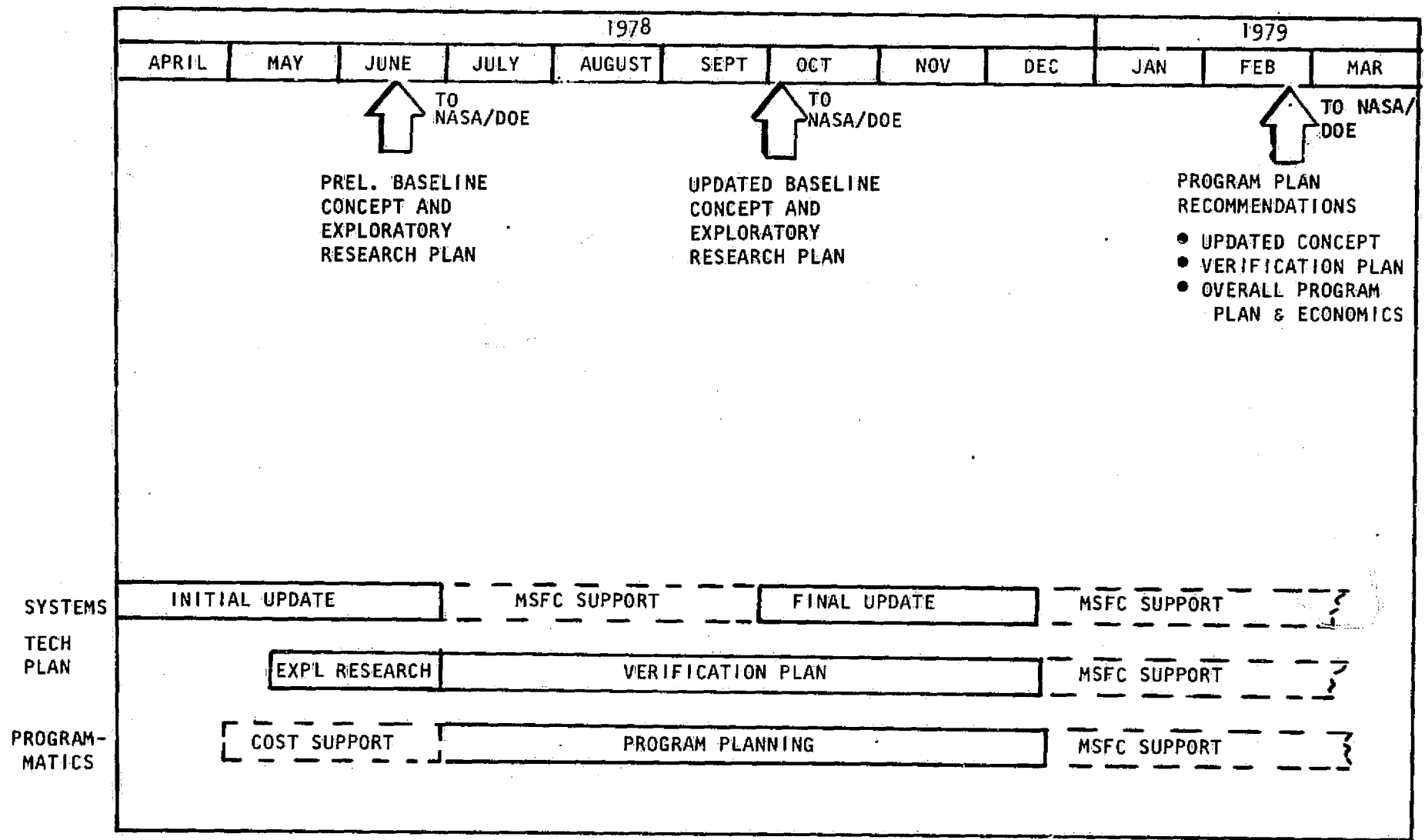
G. M. HANLEY



OVERALL SPS ACTIVITIES

This chart illustrates the relationship between this contract and NASA/DOE activities. Two system updates are planned. The first update was accomplished during the first three months of the contract. Another update is planned during October, November, and December. Exploratory research planning also has been completed, and verification planning will be accomplished from July through December. Major program planning activity will be started in July and will be completed in December.

OVERALL SPS ACTIVITIES



PRELIMINARY BASELINE SATELLITE CONCEPT

This chart shows the preliminary baseline concept designated by NASA/MSFC at the conclusion of Exhibits A and B of the SPS contract. This concept has the following major characteristics:

- GaAlAs solar cells with reflectors having a 2:1 concentration ratio
- Aluminum structure
- 5 GW power output at ground utility busbar
- Single, centrally-located microwave antenna with klystron dc-RF converters

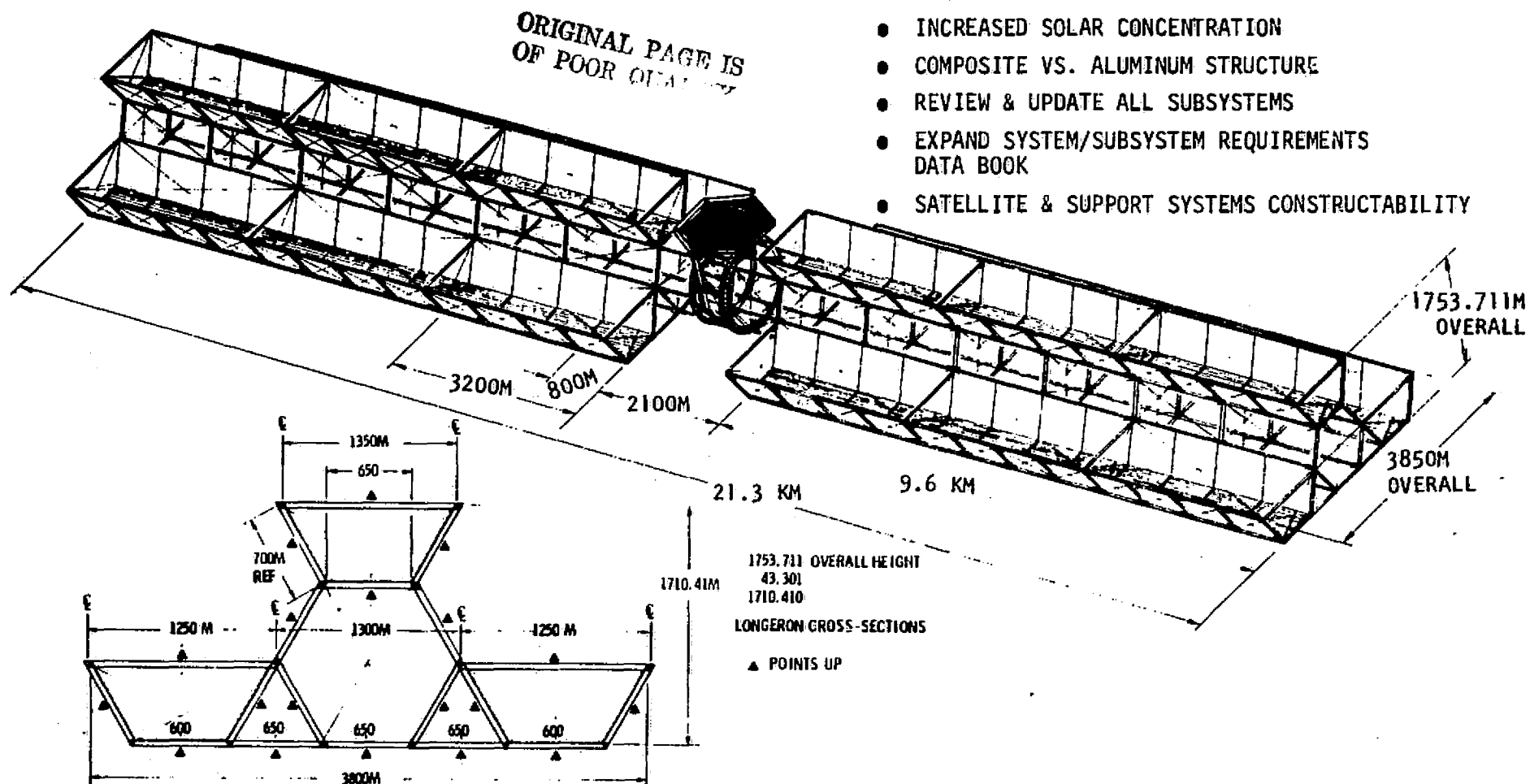
Primary effort during Exhibit C is shown on the chart. A solid state (transistor) replacement for the klystrons will be investigated to assess impacts on the SPS concept. Flat-plate concentrators giving CR up to 2.7 also will be studied. All subsystem areas will be investigated and, where appropriate, trade studies on analyses conducted to further define the satellite concept. The requirements data book, initiated during the past year, will be updated and expanded to the total systems level.

A major effort will result in a more detailed definition of satellite construction as well as construction of the required support systems.

PRELIMINARY BASELINE SATELLITE CONCEPT

MAJOR TRADE STUDIES AND PRODUCTS

- SOLID STATE ANTENNA DESIGN
- INCREASED SOLAR CONCENTRATION
- COMPOSITE VS. ALUMINUM STRUCTURE
- REVIEW & UPDATE ALL SUBSYSTEMS
- EXPAND SYSTEM/SUBSYSTEM REQUIREMENTS DATA BOOK
- SATELLITE & SUPPORT SYSTEMS CONSTRUCTABILITY

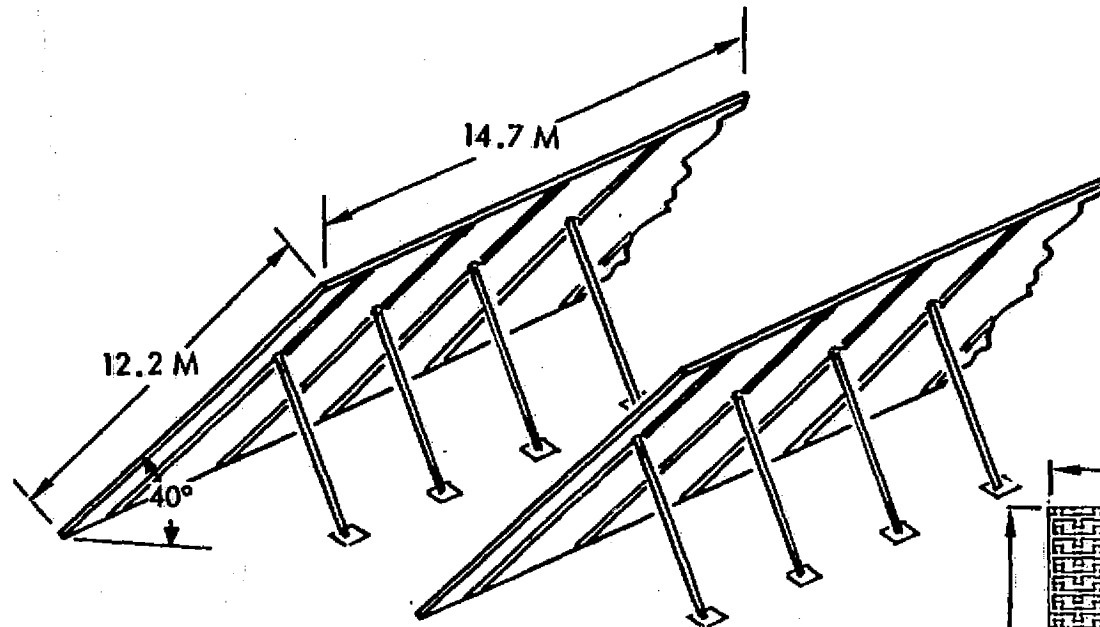


RECTENNA CONSTRUCTION

The current rectenna concept uses a phased array to increase signal strength. A stripline track collects the dipole signals at a common outlet where it is converted to dc by a diode rectifier. Alternative phased array approaches will be evaluated to select the best approach.

Rectenna construction will be updated for the selected approach. These studies will expand on previous results to include a more detailed definition of the rectenna system.

RECTENNA CONSTRUCTION

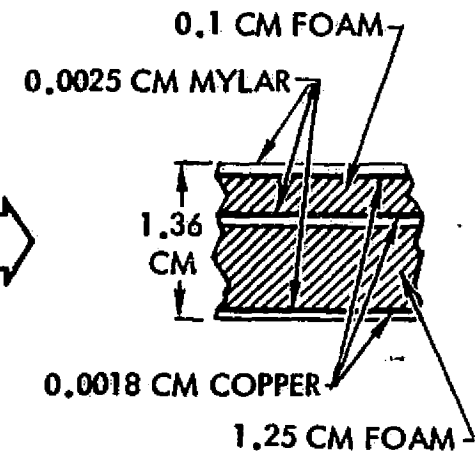
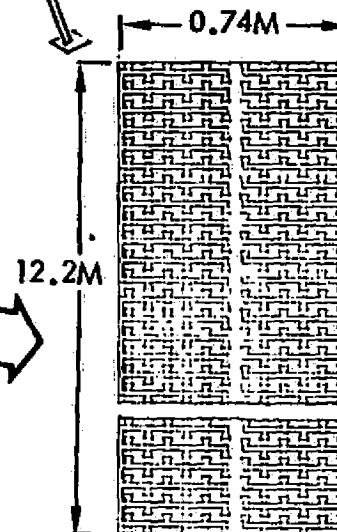


RECTENNA SUPPORT CONCEPT

MAJOR TRADE STUDIES AND PRODUCTS

- ALTERNATIVE PHASED ARRAY APPROACHES EVALUATION
- RECTENNA CONSTRUCTABILITY

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RECTENNA MODULE

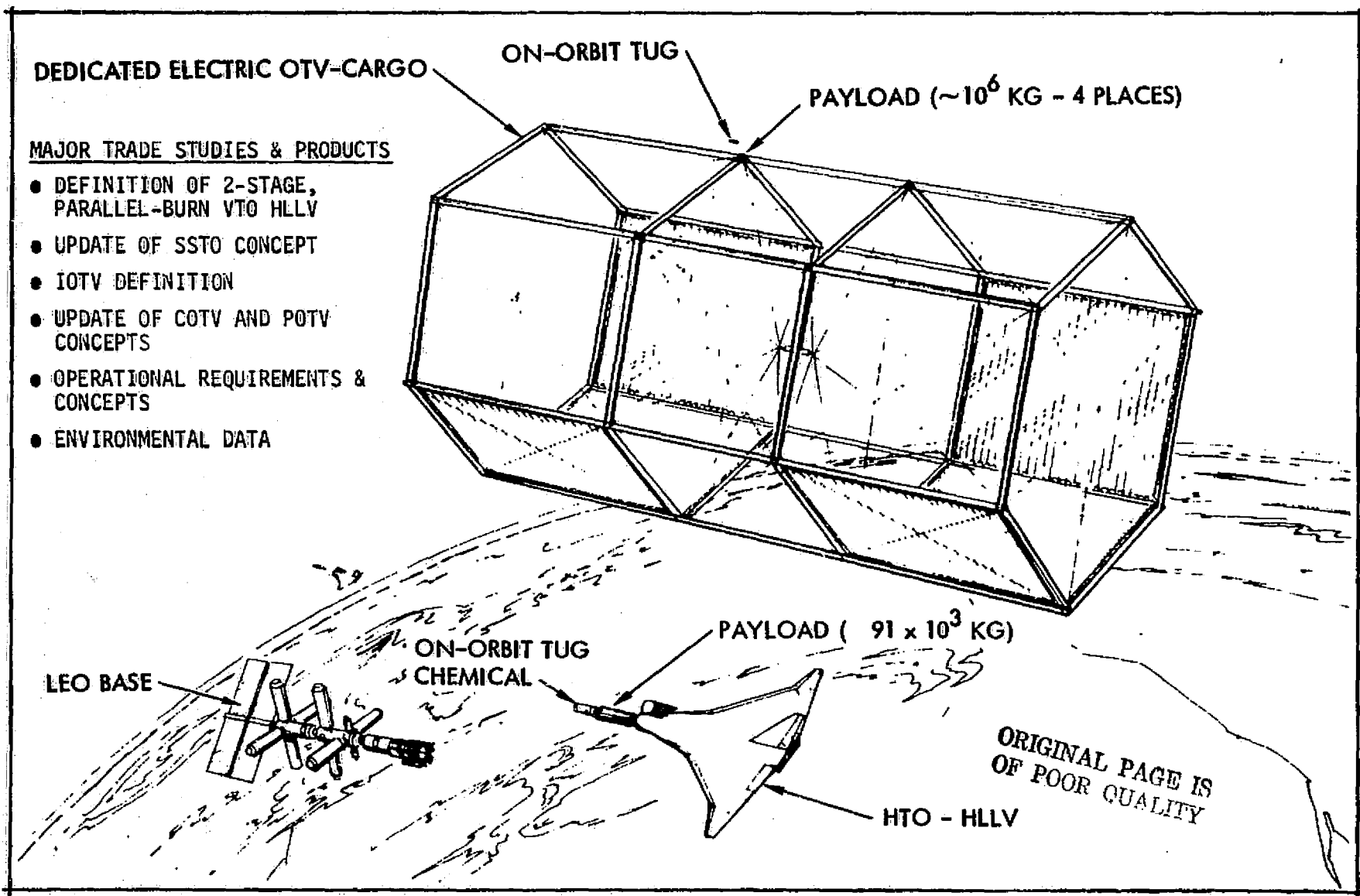


PRELIMINARY BASELINE TRANSPORTATION SYSTEMS CONCEPT

The preliminary baseline transportation concept included the elements shown on this chart: a horizontal take-off SSTO HLLV, a cargo orbit transfer vehicle that uses solar electric power with argon ion-bombardment thrusters, a small, chemical (LO_2/LH_2) intra-orbit transfer vehicle (IOTV), and a chemical (LO_2/LH_2) personnel orbit transfer vehicle (POTV).

During this study, major HLLV attention will be given to a VTO, 2-stage, parallel-burn vehicle. The SSTO concept will be updated to include additional analysis of the propulsion system, and mass properties and an updating of the vehicle performance. A preferred IOTV concept will be selected and the electric COTV and chemical POTV concepts will be updated. In addition overall operational requirements and concepts and environmental data will be developed.

PRELIMINARY BASELINE TRANSPORTATION SYSTEM CONCEPT



STUDY SCHEDULE

Task 1.0 of the study has the objective of characterizing, theoretically, the circuit for the solid state microwave antenna dc-RF conversion devices. Waterloo University, located in Canada, will conduct this effort under subcontract. During the first 3 months of the contract, the effort at Rockwell was focused on development of preliminary solid state transistor design characteristics as an input to the Waterloo effort.

Task 2.0 of the study is concerned with several studies requiring special emphasis which are indicated as outputs. During the first 3 months of the study, emphasis was put on an analysis of satellite constructability (and to a limited extent on satellite support systems constructability) and an overall manufacturing analysis.

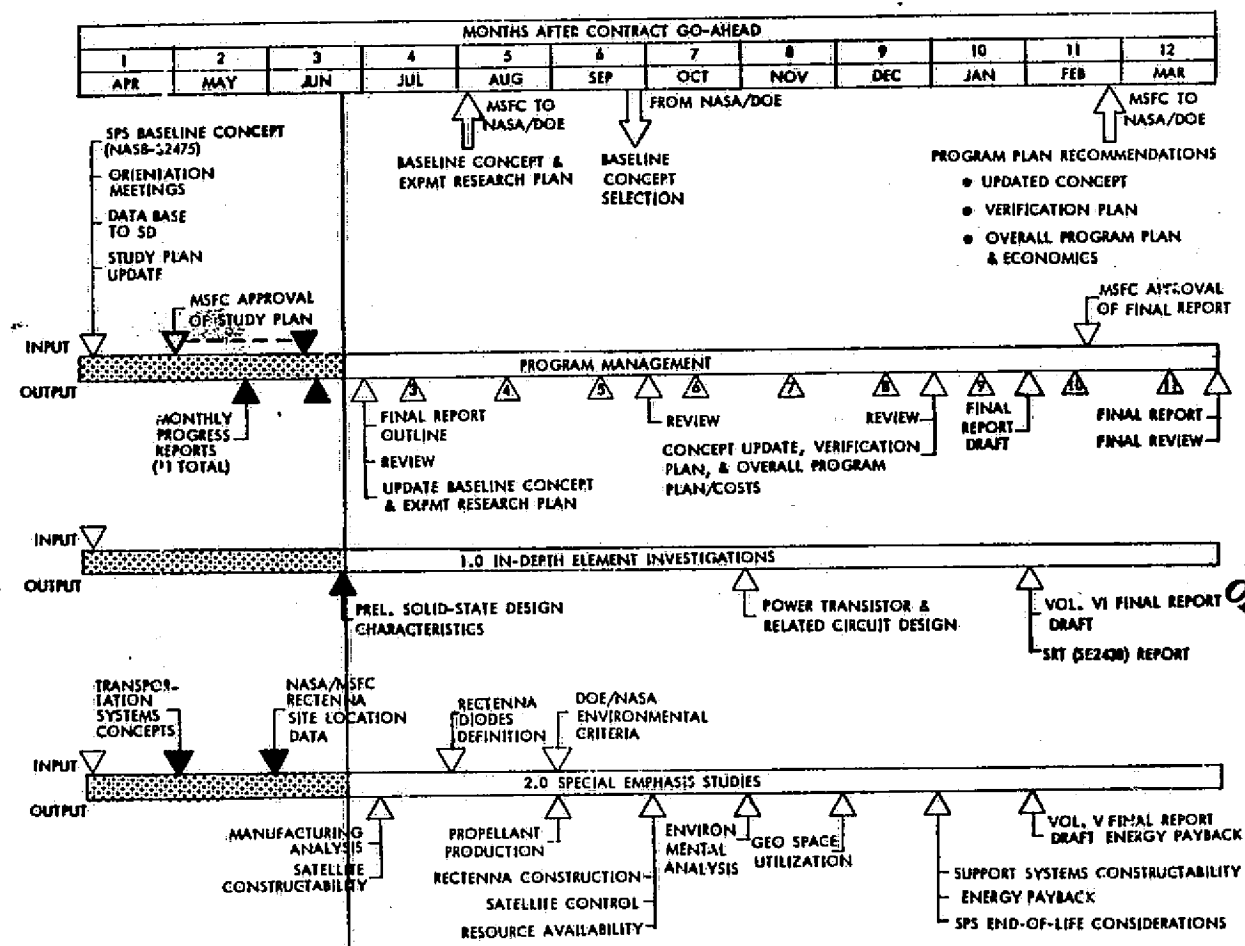
Task 3.0, Transportation Analysis, is concerned with the overall definition of the space transportation elements of the operational SPS. Main emphasis during the first 3 months was placed on definition of a preliminary 2-stage VTO HLLV concept and an intra-orbit transfer vehicle. The SSTO HLLV update shown in late October was also virtually completed during this period.

Task 4.0 is concerned with definition of an experimentation/verification program. During the first 3 months, emphasis has been put on recommendations for experimental research.

Task 5.0 is the centroid of overall SPS system engineering and integration. During the first 3 months, studies were concentrated on an overall updating of the SPS system and subsystems. Areas of major emphasis in these studies include: (1) initiation of a thermal/dynamic analysis using the NASTRAN computer program, (2) definition of a solid-state antenna design, and (3) evaluation alternative of rectenna concepts.

During the first 3 months, the Task 6.0 (Cost and Economics) have been concentrated on schedule, cost, and economics updating and a listing of technology control milestones.

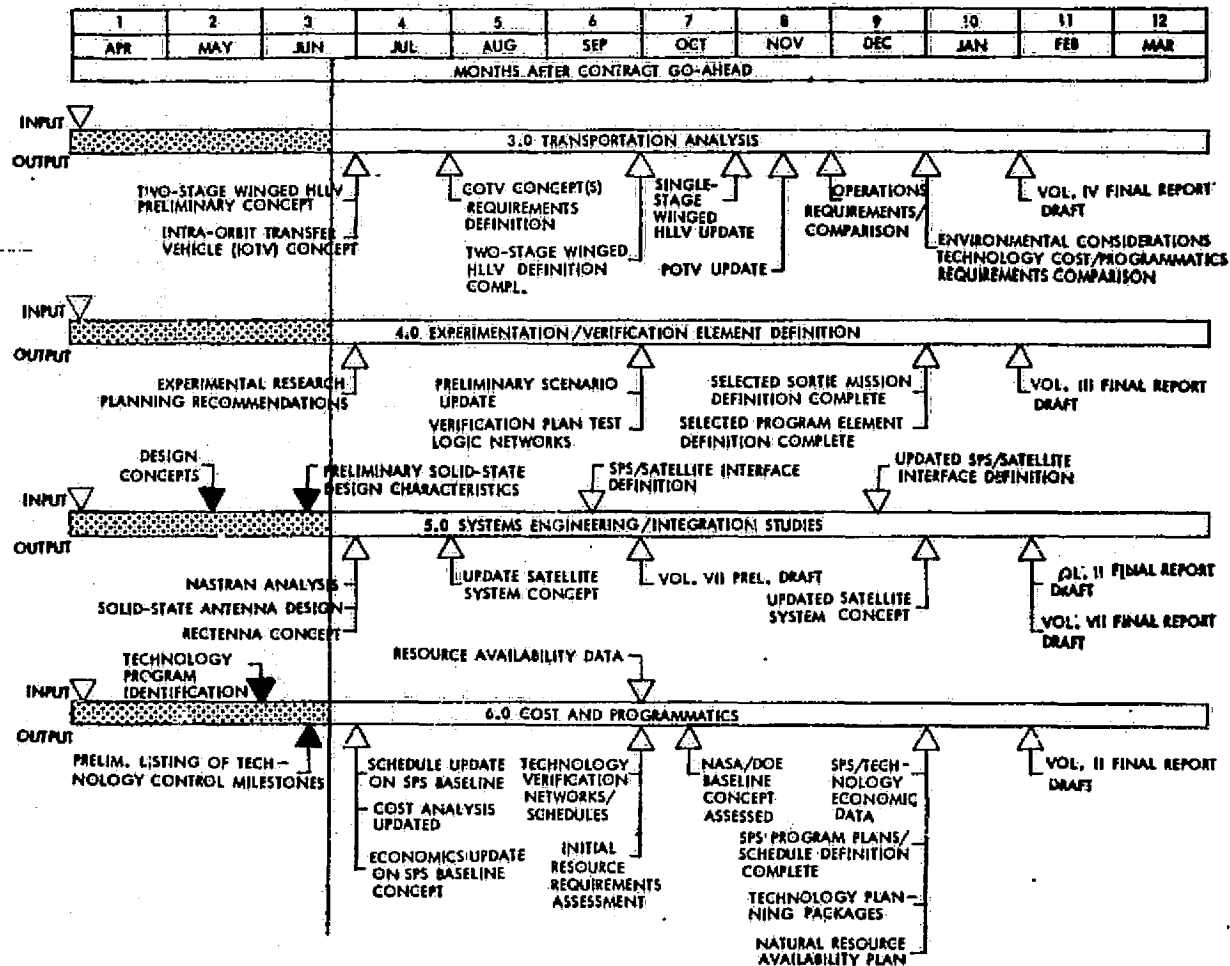
SPS CONCEPT STUDY SCHEDULE



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SPS CONCEPT STUDY SCHEDULE (CONT.)



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MAJOR AREAS OF PROGRESS

This chart is self-explanatory.

MAJOR AREAS OF PROGRESS

SYSTEM ENGINEERING

- SUBSYSTEM REVIEW & UPDATE COMPLETED & IMPACTS ASSESSED
- PRELIMINARY SOLID STATE DC-RF CONVERSION SPS CONCEPT DEFINED
- ALTERNATIVE RECTENNA CONCEPTS IDENTIFIED
- SATELLITE STRUCTURAL DYNAMICS STUDY INITIATED TO COMPARE ALUMINUM AND COMPOSITE STRUCTURES

SPECIAL EMPHASIS STUDIES

- SATELLITE AND SUPPORT SYSTEMS CONSTRUCTABILITY FURTHER DEFINED
- ANALYSIS OF SPS PRODUCTION CONDUCTED

TRANSPORTATION STUDIES

- PRELIMINARY TWO-STAGE, PARALLEL-BURN VTO CONCEPT DEVELOPED
- SSO CONCEPT PERFORMANCE UPDATED

PROGRAM PLANNING

- PRELIMINARY EXPERIMENT/VERIFICATION PLAN DEVELOPED
- COST AND ECONOMIC DATA UPDATED



SYSTEM STUDIES

A review of the current design was made and areas identified for further study. This chart summarizes some preliminary assessments of areas for further analysis. Major impacts for concern were cost, mass, and design complexity. Primary emphasis was on reducing overall cost.

SYSTEM STUDIES

SUBSYSTEM/ELEMENT	ANALYSIS/TRADE	MAJOR IMPACT/CONSIDERATION
SOLAR ARRAY	● SOLAR CELL PERFORMANCE ● B.O.L. POWER ● SOLAR CELL COST ● E.O.L. REFLECTIVITY ● CONCENTRATION RATIO ● EARLY VERIFICATION	● GaAs SINGLE CRYSTAL CELL STILL PREFERRED ➤ BEST FOR FUTURE MAY BE GaAs MULTIPLE BAND GAP POLYCRYSTALLINE ● EXCESS SOLAR ARRAY POWER SHOULD BE UTILIZED ~297 MW (AVG), 490 MW (PEAK) ● GROUND STORAGE LOOKS MARGINAL ● E.O.L. REFLECTIVITY INCREASED FROM 0.72 TO 0.83 ~500 MW GAIN ● STAY WITH 60° SLANT ANGLE ● CR=2 OFFERS COST ADVANTAGE
POWER DISTRIBUTION	● EFFICIENCY CHAIN ● LOW VOLTAGE REQMT ● BLOCK DIAGRAMS & POWER CONTROL ANALYSIS	● ηO.A. REDUCED FROM 6.06% TO 5.78% ● VERY DIFFICULT TO PROVIDE 40 KV TO 40 VDC (SOLID STATE) ~0.5-1 KG/KW ● INITIAL INTERFACES; START OF INTEGRATED BLOCK DIAGRAM
STRUCTURES	● NASTRAN ANALYSIS	● INCREASED NUMBER OF BRACES FOR STABILITY ● PRELIMINARY STRESS ANALYSIS DESIGN LOOKS O.K.



SYSTEM STUDIES (CONTINUED)

SUBSYSTEM/ELEMENT	ANALYSIS/TRADE	MAJOR IMPACT/CONSIDERATION
THERMAL	● POWER CONDITIONING COMPONENT ANALYSIS ● SOLID STATE DEVICE ANALYSIS	● THERMAL CONTROL RADIATORS FOR VOLTAGE CONVERTERS ~ 10⁶ KG MASS INCREASE ● THERMAL CONTROL CONCEPT FOR TRANSISTOR POWER MODULES ~2X DEVICE WEIGHT
ANTENNA	● SOLID STATE DC/RF CONVERSION	● 50 KW SOLID STATE POWER MODULE CONCEPT ● EFFICIENCY DC-RF 80-85% WAS 85%; POWER DISTRIB. 80-95% WAS 96%
RECTENNA	● STRIP LINE VS "BACKFIRE" COAXIAL ● UTILITY INTERFACE AC VS DC ● DC TO AC CONVERSION CONCENTRATED VS DISTRIBUTED	● STAY WITH STRIP LINE ● AC FOR < 300 MILES; DC FOR > 800 MILES ● CONTROLLED QUASI-SINEWAVE DEVELOPED FROM RECTENNA ARRAY SEGMENTS LOOKS ATTRACTIVE (DISTRIBUTED CONCEPT).



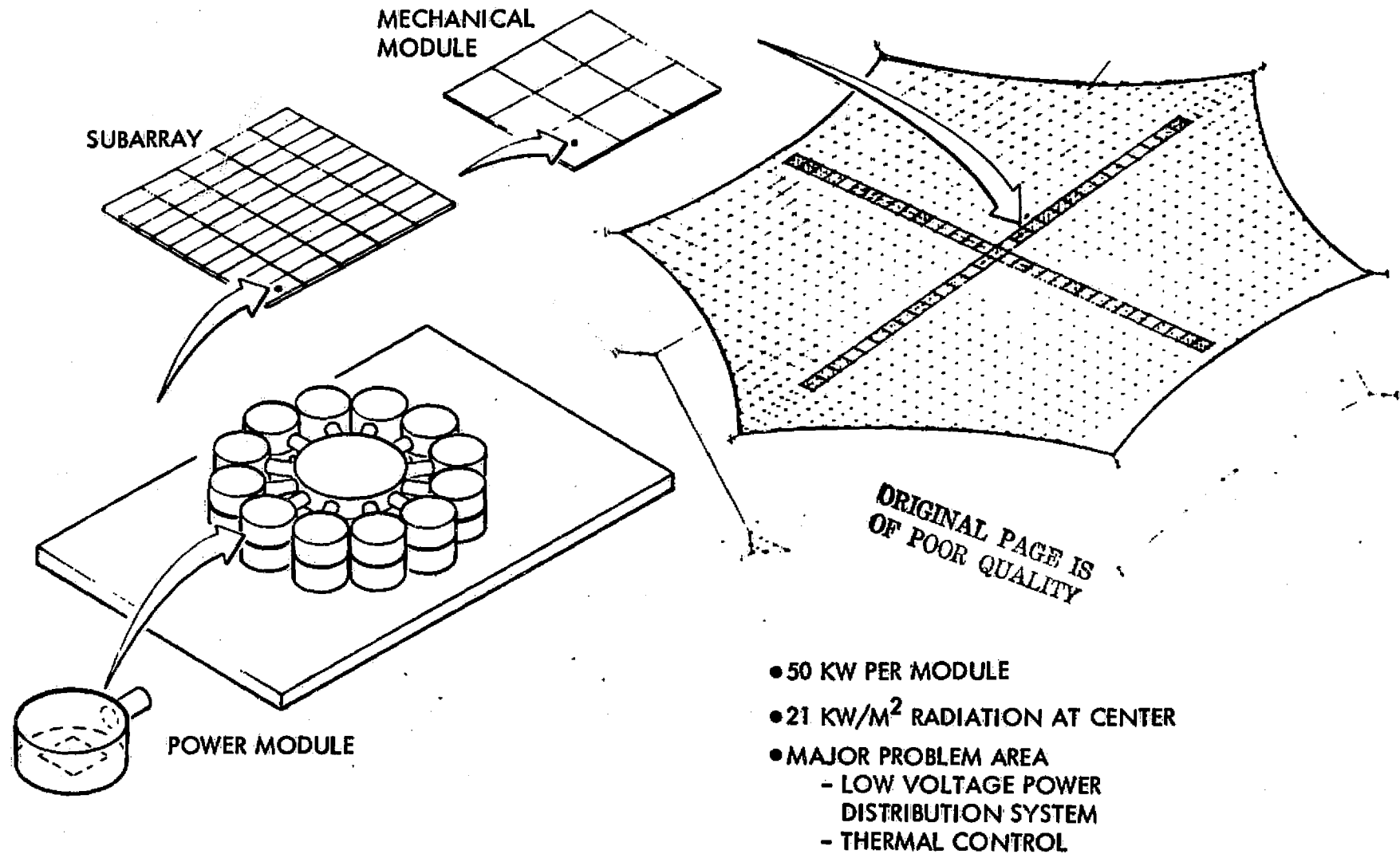
SOLID STATE ANTENNA CONCEPT

The antenna array is composed of a series of modular units of diminishing size. The major unit is the mechanical module which consists of a graphite-epoxy structure. The structure is attached to the dual set of crossed catenary cables, which are attached to a compression frame at the array edge and form a tension-web (trampoline structure). Each 30.62×92 -m mechanical module is an assembly of nine 10.20×11.64 -m subarrays. Each subarray is a radiating element in the total array. As such, it has a single transmitting phase which is set by the retro-electronics associated with the subarray.

The subarrays are formed out of power modules. Each power module has a single dc-to-microwave converter together with its associated radiator. In the point design, these are resonant cavity radiators (RCR's). There are ten types of power modules, all with converters of the same power, but differing in size.

A typical power module assembly consisting of a 50 kW, solid state dc-RF converter installed on a typical power module is also illustrated.

SOLID STATE ANTENNA CONCEPT



ALTERNATIVE SOLID STATE ANTENNA CONCEPTS

The present satellite point design utilizes HV klystron dc-RF converters to convert the dc power generated to the 2.45 GHz microwave state. The power for the RF converters is transferred at 40 kV dc (nominal) across the antenna slip rings, converted to five selected HV dc voltages and utilized by the klystrons.

Solid state dc-RF converters require an input voltage of less than 100 V (present design indicate an input voltage of approximately 40 V dc). If the appropriate voltage (40 V dc) is generated the current carrying capacity of the rings would need to be prohibitively large (one-half of approximately 10 GW @ 40 V $\approx 125 \times 10^6$ amps). If relatively high voltage is generated (20-40 kV dc) and transferred across the rings, the subsequent dc-dc conversion results as large increases in antenna mass ($10-20 \times 10^6$ kg) considering both the conversion elements and the additional thermal control requirements.

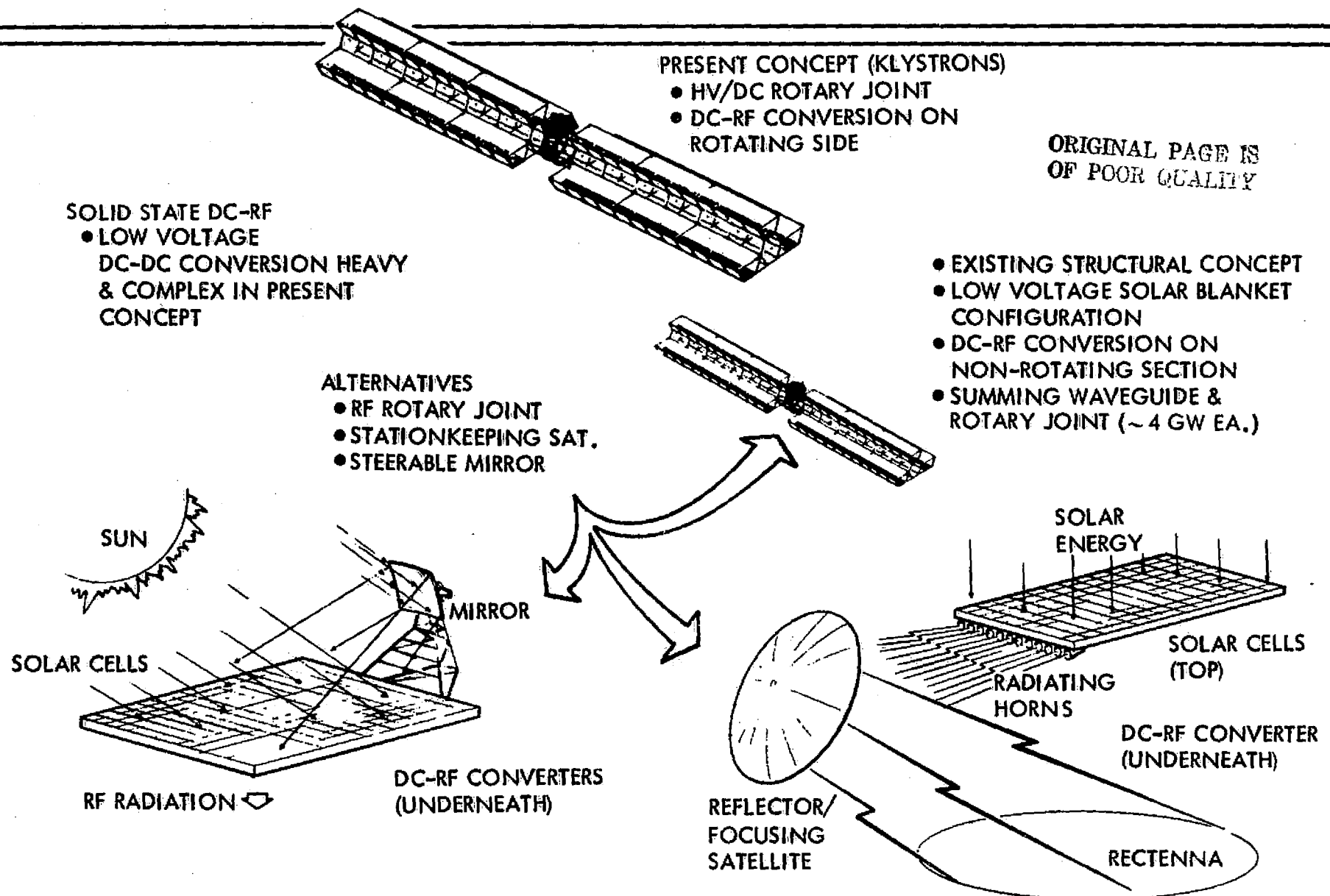
It was therefore concluded that the present satellite design concept was not compatible with a solid state dc-RF converter concept. Three alternate configuration concepts are identified which eliminate the power distribution effects but still present significant design problems although these are now in different areas. All three concepts restructure the solar blanket configuration to develop the low voltages required by the solid state devices and locate the dc-RF converters immediately adjacent to the solar blankets to reduce I^2R losses.

In the first alternative satellite the construction form is the same as the point design, however, the summed RF energy must now be transferred over a waveguide rotating joint with a capacity of over 4 GW @ 2.45 GHz.

The second alternative completely restructures the satellite and requires that the plane of the solar blanket be sun stabilized. The collected RF energy is transmitted to a free-flying stationkeeping satellite and retransmitted to the receiving rectenna. In order to control the RF beam it will be necessary to provide extremely precise stationkeeping and pointing/focusing control.

The third alternative shown is similar to the second except that the satellite is stabilized to the rectenna boresite and the variable sun angle is compensated for by using an attached (or if desirable a free-flying) reflecting mirror. The point accuracies required for this concept would be significantly less than for the second alternative.

ALTERNATIVE SOLID STATE ANTENNA CONCEPTS



MASS PROPERTIES STATUS

The mass of the current SPS versus Exhibit A/B are shown in the chart, and has resulted in an 8.3% increase in dry weight. The following tabulation identifies the reasons for these mass changes:

Collector Area

Primary structure—Eighteen additional 50-m tribeams across top of reflector bays.

Attitude control—Updated to reflect final Exhibit A/B.

Power conditioning equipment—Addition of 40,000 low-voltage converters plus increase in switch gears due to drop in system efficiencies.

Power distribution—Increase in conductors and slip rings due to drop in system efficiencies.

Antenna Section

Primary structure—Duplication in slip ring support.

Thermal control—Radiator system added (320,000 m²) for high-voltage converters.

Power conditioning equipment—Addition of 144,000 low-voltage converters and 136,000 regulators plus increase in switch gear due to lower system efficiencies.

Power distribution—Decrease in conductors and brushes due to drop in system efficiencies.

MASS PROPERTIES SUMMARY (KG X 10⁻⁶)

SUBSYSTEM	END OF EXHIBIT A/B	CURRENT	Δ
COLLECTOR ARRAY	(13.919)	(14.169)	(+ 0.250)
STRUCTURE & MECHANISM	3.777	3.825	+ 0.048
ATTITUDE CONTROL	0.095	0.116	+ 0.021
POWER SOURCE	8.831	8.831	—
PDC	1.166	1.347	+ 0.181
IMS	0.050	0.050	—
ANTENNA SECTION	(14.204)	(16.297)	(+ 2.093)
STRUCTURE & MECHANISM	1.685	1.682	— 0.003
THERMAL CONTROL	1.408	2.457	+ 1.049
MICROWAVE POWER	7.012	7.012	
PDC	3.469	4.516	+ 1.047
IMS	0.630	0.630	
TOTAL SPS	28.123	30.466	+ 2.343
GROWTH (30%)	8.437	9.140	+ 0.703
TOTAL SPS (WITHGROWTH)	36.560	39.606	+ 3.046



MAJOR SATELLITE CONSTRUCTION ELEMENTS

This chart is self-explanatory.

MAJOR SATELLITE CONSTRUCTION ELEMENTS

STRUCTURE

{
2 M BEAMS
50 M TRIBEAMS
INTEGRATED FRAMES & LONGERONS
ACS
CENTER STRUCTURE

SOLAR CONVERTER

{
BLANKETS
REFLECTORS
CONDUCTORS
DATA MGMT & CONTROLS

MW ANTENNA

{
RCR PANELS
KLYSTRONS
MECH MODULES
CONDUCTORS
DATA MGMT & CONTROLS



SATELLITE CONSTRUCTION BASE (SCB)

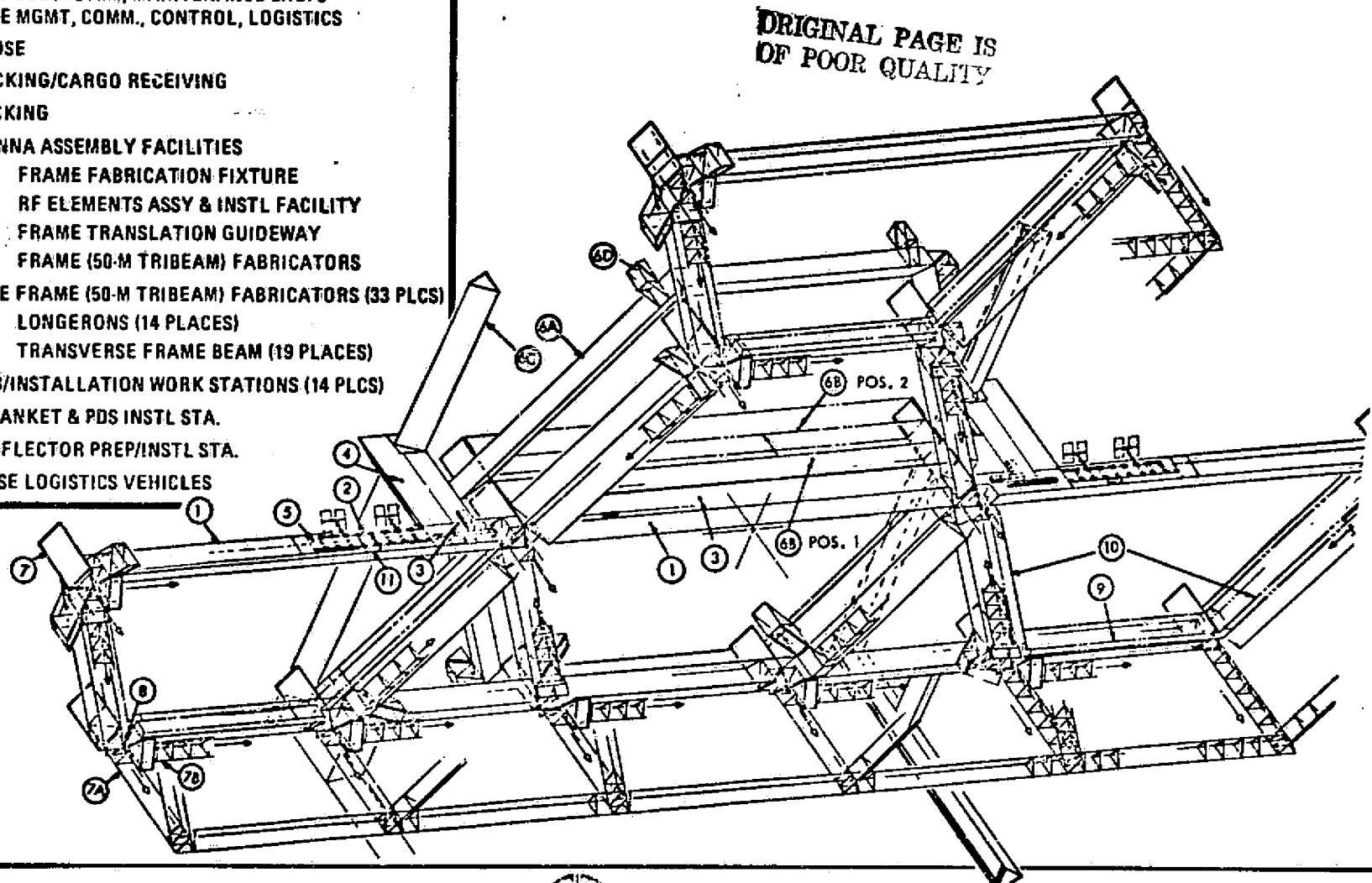
Construction of the satellites takes place in GEO, each satellite being constructed at its designated longitudinal location. All construction activities are supported by a single integrated construction base which produces satellites at the rate of 4 per year (and later 5 per year) during the mature portion of the program. Upon completion of one satellite the base is moved to the operational location of the next satellite for construction of that satellite.

The construction base consists of the satellite construction fixture, the construction equipment, and the base support facilities and equipment. The construction fixture is a rugged heavy gage metal structure on which all elements of the construction base are mounted. The fixture constitutes the reference surfaces for the construction operations and the locating jig for the equipment which constructs/installs various elements of the satellite in situ.

The major construction equipment includes the 50 m tribeam fabricators; the deployment equipment for the solar cell blankets, the solar reflector panels, the power distribution conductors, the cables for retention of the solar blankets, and the structure tensioning cables; the assembly facility for the MW antenna mechanical modules; and the equipment for installation of the MW antenna elements into the antenna frame. The location of most of these elements is identified on the chart.

SATELLITE CONSTRUCTION BASE (SCB) (GEO LOCATED)

- ① CONSTRUCTION FIXTURE
- ② BASE SUPPORT FACILITIES & EQUIP (2 EA)
340-CREW MEMBER SUPPORT
BASE SUBSYSTEM, MAINTENANCE SHOPS
BASE MGMT, COMM., CONTROL, LOGISTICS
- ③ WAREHOUSE
- ④ EOTV DOCKING/CARGO RECEIVING
- ⑤ POTV DOCKING
- ⑥ MW ANTENNA ASSEMBLY FACILITIES
 - ⑥A FRAME FABRICATION FIXTURE
 - ⑥B RF ELEMENTS ASSY & INSTL FACILITY
 - ⑥C FRAME TRANSLATION GUIDEWAY
 - ⑥D FRAME (50-M TRIBEAM) FABRICATORS
- ⑦ SATELLITE FRAME (50-M TRIBEAM) FABRICATORS (33 PLCS)
 - ⑦A LONGERONS (14 PLACES)
 - ⑦B TRANSVERSE FRAME BEAM (19 PLACES)
- ⑧ BEAM FAB/INSTALLATION WORK STATIONS (14 PLCS)
- ⑨ SOLAR BLANKET & PDS INSTL STA.
- ⑩ SOLAR REFLECTOR PREP/INSTL STA.
- ⑪ INTRA-BASE LOGISTICS VEHICLES



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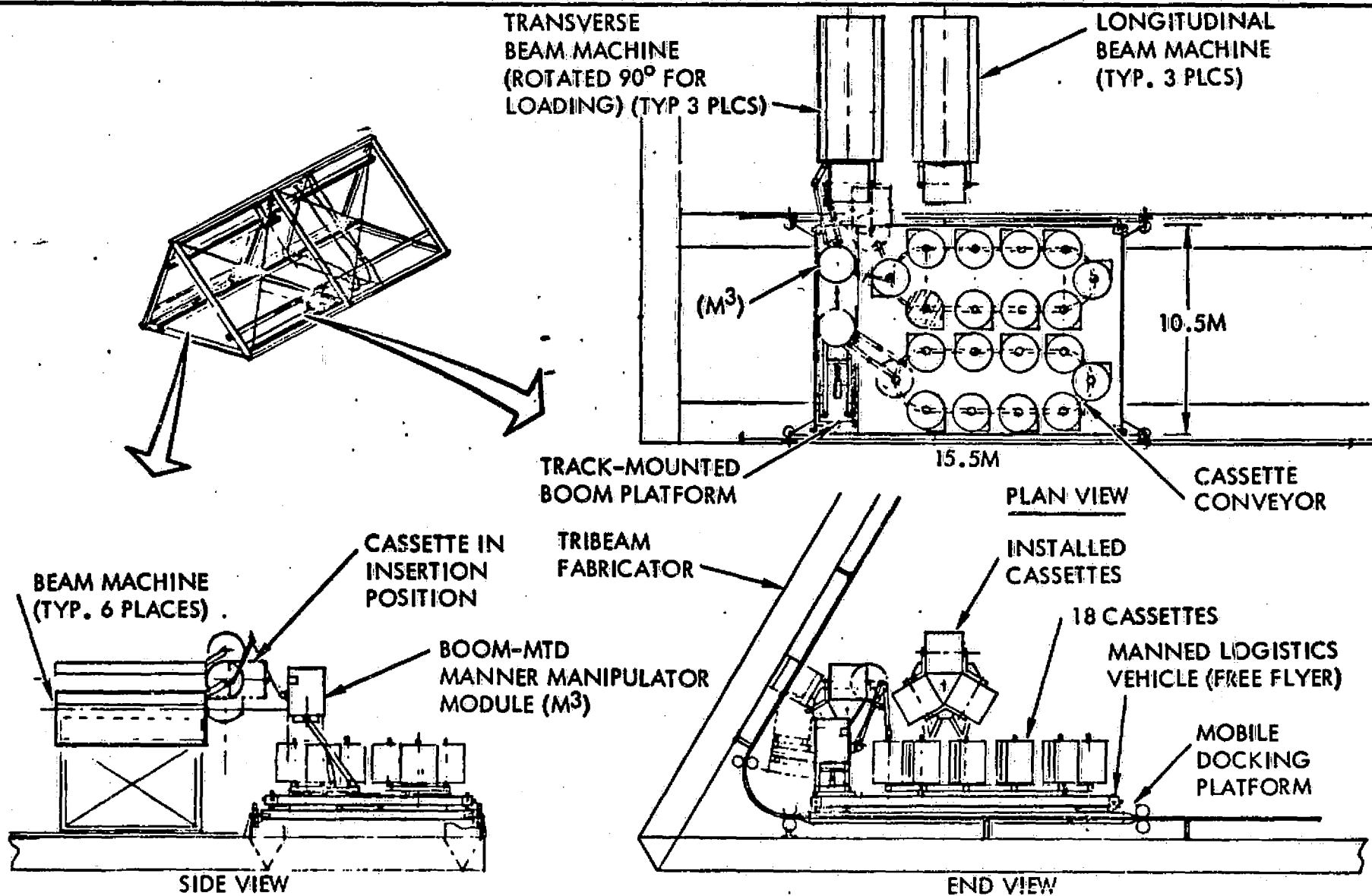
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TRIBEAM FABRICATOR SERVICING CONCEPT

There are 33 tribeam fabricators utilized for satellite construction. These fabricators are installed in 14 general locations. Each fabricator must be loaded with 18 aluminum cassettes (3 per each of 6 beam machines) twice to support construction of one satellite, since the cassettes are sized to provide material for one wing only. The cassettes are transported from the warehouse area of the SCB to the various locations. This can be done either by a vehicle traveling on tracks or cables, or by a free flier. The network of tracks (or cables) which would be required for servicing the various locations from the warehouse area is complex and involves numerous changes of direction, some of which would be difficult to traverse. For these reasons, the free flying mode was selected. The concept consists of a chemically propelled and stabilized manned logistics vehicle (LV) capable of transporting 18 cassettes. The cassettes are attached to a conveyor on a detachable flatbed, which permits preparation of one load while the other is being delivered. The loaded LV docks on a track-mounted magnetic docking pad located at the rear of the fabricator. The tracks traverse the three sides of the fabricator, thus providing access by the LV to the six beam machines. Each empty cassette, mounted in a swivel hub and secured at the other end by a yoke arrangement, is removed and replaced by a full cassette. It is noted that the beam machines which construct the cross beams rotate and translate into position parallel to the longitudinal machines to facilitate unloading and loading.

The initial loading operation is conducted during preparation of the SCB for the next satellite construction. The second operation is conducted following completion of the first wing. Sufficient LV's are available to permit accomplishment of the 8 hour operation at the various stations within the overall construction time line. LV propellant requirements are minimal, amounting to approximately 850 kg per sortie.

TRIBEAM FABRICATOR SERVICING CONCEPT



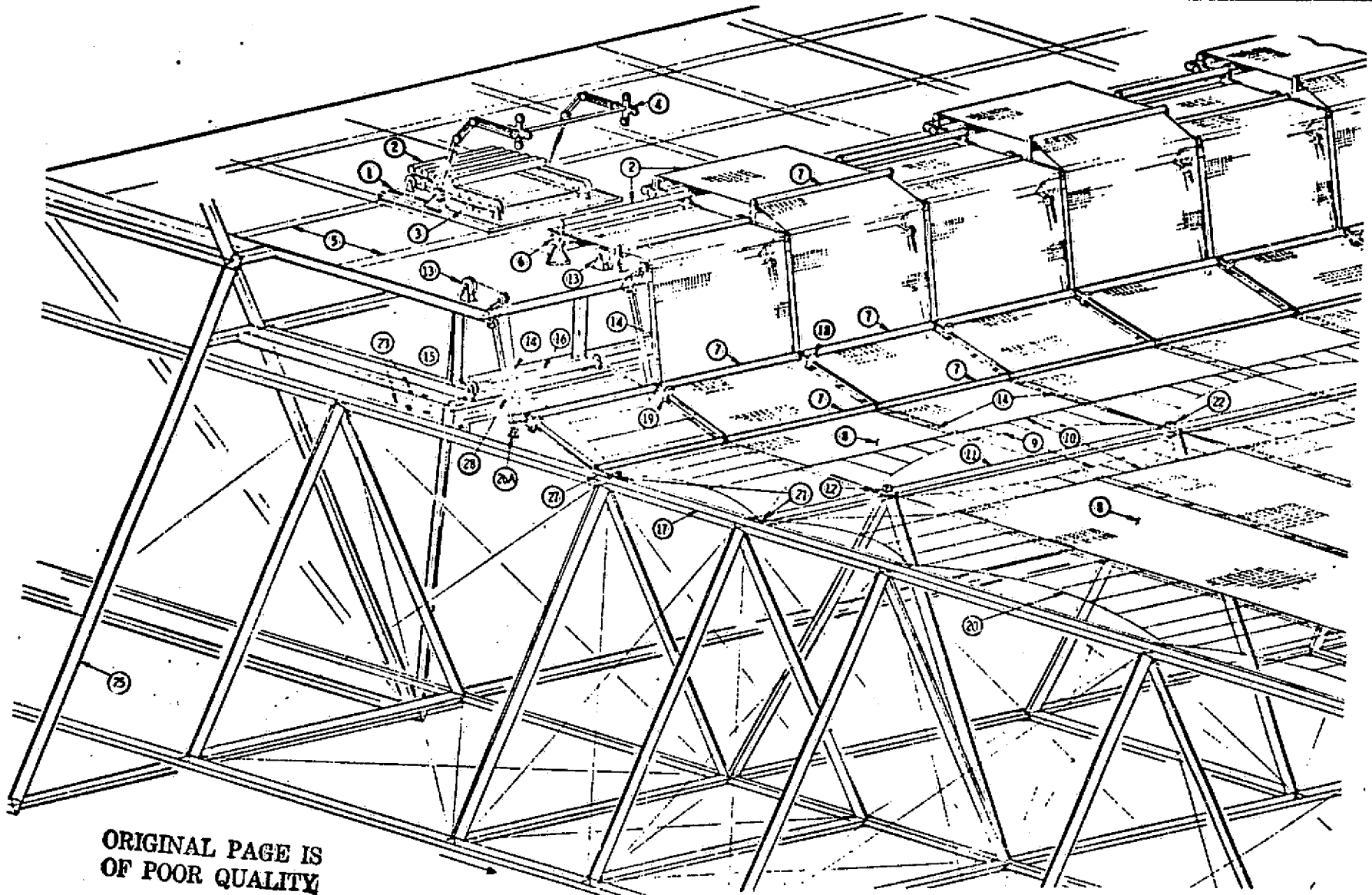
SOLAR BLANKET INSTALLATION CONCEPT

The solar blanket in each 800 m long bay is a structurally independent installation suspended by side and end catenaries attached to the longerons and cross beams respectively, and by longitudinal cables stretched between the blanket strips. Each blanket strip is approximately 25 m wide and 750 m long, and is packaged in a 25 m wide roll by 0.6 m in diameter. Each two bays of solar blankets are electrically connected in series, constituting a functional module which produces the required voltage.

Initially the blanket rolls are transported from the SCB warehouse area by a transporter/loader (1) which inserts the rolls into the dispensers (6). The leading edge of the blanket strips with end catenaries attached, are then threaded through the roller arrangement and attached to the trailing edge of the cross beam just completed. The longitudinal cables to which the side edges of the blanket will be fastened are threaded from the cable dispenser (13) and attached in a similar manner. The longitudinal catenaries are fabricated on the middle deck, fed into the dispensing spindle (15) and then attached to the cross beam trailing edge.

Solar blankets and catenaries are attached to the longitudinal cables by fold-over tabs which are applied by automatic fastening equipment. As the cross beam advances the blanket strips, longitudinal catenaries cables are payed out. The two outside cables are attached to the longitudinal catenaries, the two longitudinal catenaries to their respective longerons, and the inside edges of adjacent blanket strips to their stabilizing cables. Upon completion of the bay and the next following cross beam, the trailing edges of the blankets (i.e., the trailing transverse catenaries) and the trailing end of the longitudinal catenaries are attached to the leading edge of that cross beam. The installation is then tensioned and electrical connections completed.

SOLAR CELL BLANKET INSTALLATION CONCEPT



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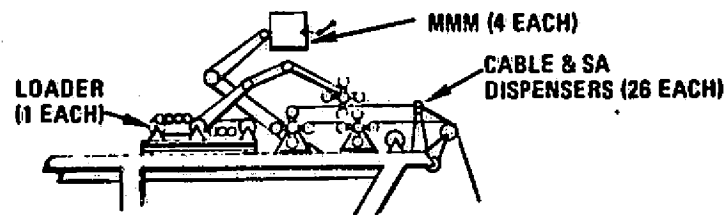
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MANNED OPERATIONS AT SOLAR BLANKET INSTALLATION STATIONS

The primary operations occurring at the upper, middle, and lower deck stations during beam fabrication and solar blanket installation are identified. The locations of the manned manipulator modules (MMM) required to support the installations also are shown. These modules are mounted on transverse tracks and are spaced so that each module services approximately one fourth of the 27 installation stations across the span of the crossbeam.

MANNED OPERATIONS AT SOLAR BLANKET INSTALLATION STATIONS

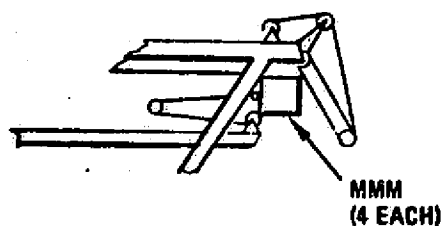
UPPER DECK



- DELIVER SA ROLLS TO LOADER
- LOADER INSERTS ROLLS IN DISPENSERS
- ROLLS THREADED THRU ROLLER SYSTEM
- DISPENSER MONITORING

4 MEN

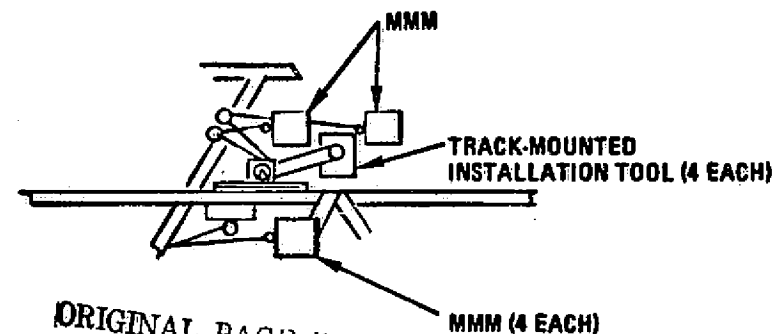
MIDDLE DECK



- FABRICATE & THREAD LONG CATENARY
- CATENARY/CABLE ATTACH MONITORING

4 MEN

LOWER DECK



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- INSTALL SADDLE CLAMPS
- INSTALL SWITCH GEARS, SM & RAC ASSP
- INSTALL INSULATION MOUNTS
- ATTACH & TENSION SA'S
- INSTALL FEEDER & DM&C BUS
- MAKE ELECTRICAL CONNECTIONS

12 MEN



MW ANTENNA INSTALLATION CONCEPT

The rf assembly and installation facilities and sequence of operations are depicted in the next three charts. The antenna waveguide subarray panels, klystrons, and electronic modules are delivered to the rf assembly and installation facility, Item 6B, in the packaged configurations. A matrix identifying installation location on the antenna suspension web for each mechanical module by file and row number is given in View A. The rf assembly and installation facility, 6B, is behind the antenna in View A. View B, looking down from the top edge of the antenna, shows that the rf facility is supported at each end from the satellite fabrication fixture structure, and that it spans the full width of the antenna. The numbers across the top surface of the facility indicate the locations of 15 identical work stations for processing the incoming rf elements preparatory to assembly into the 30.6-m $\times$ 34.92-m mechanical module configurations. The antenna frame with its module support web installed translates downward in its guideways, (6C) bringing each row sequentially in front of the rf facility.

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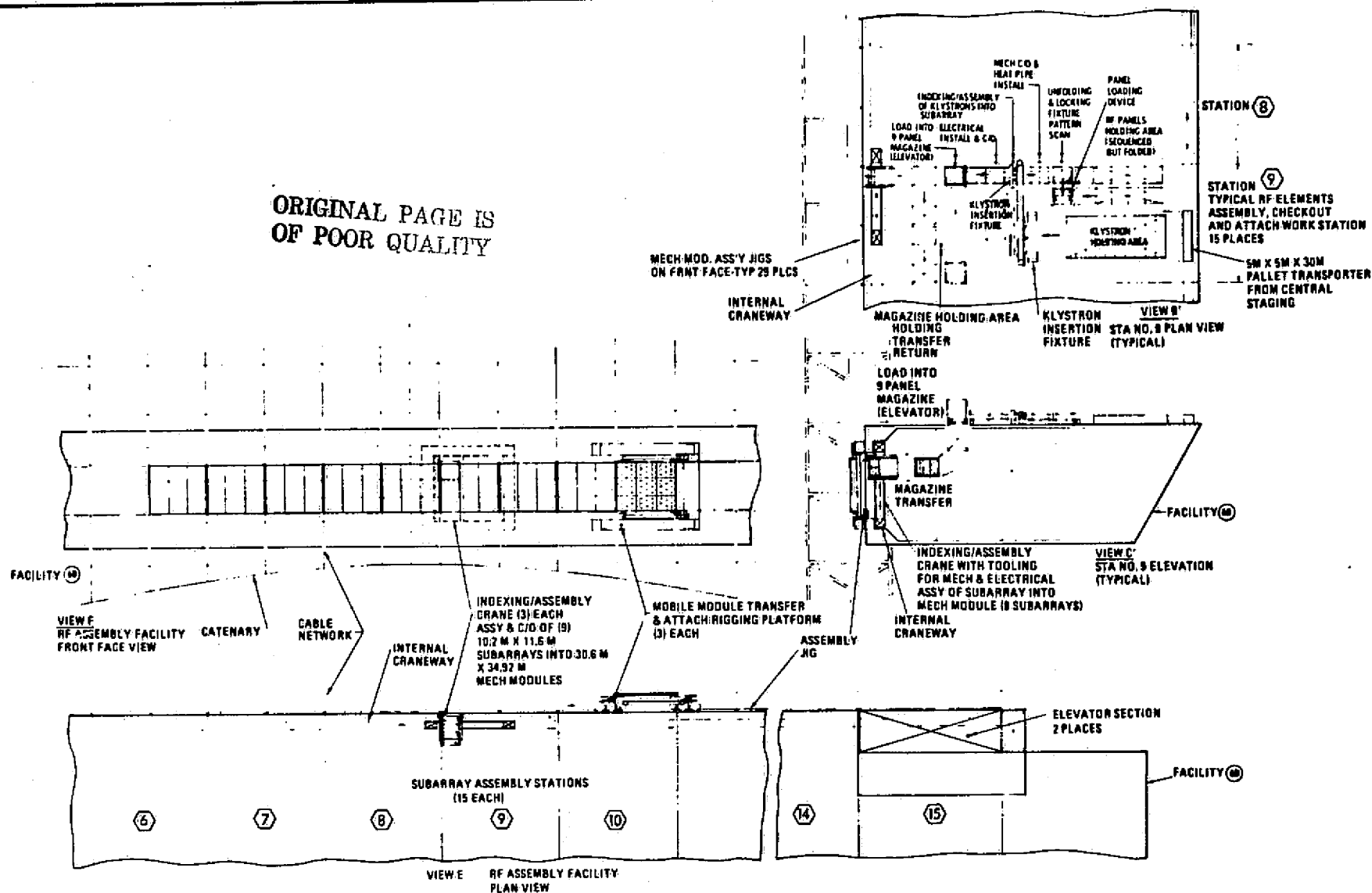


MW ANTENNA ASSEMBLY AND INSTALLATION FACILITY

This chart shows a plan view of the facility. Twenty-nine mechanical module assembly jigs, located for alignment with the twenty-nine files on the antenna, are utilized to assembly the mechanical modules from the sub-arrays. These jigs are serviced by three mobile cranes. Three mobile transfer and attach units travel the external front face of the rf facility and have access to each module jig and to each antenna file.

MW ANTENNA ASSEMBLY & INSTALLATION FACILITY

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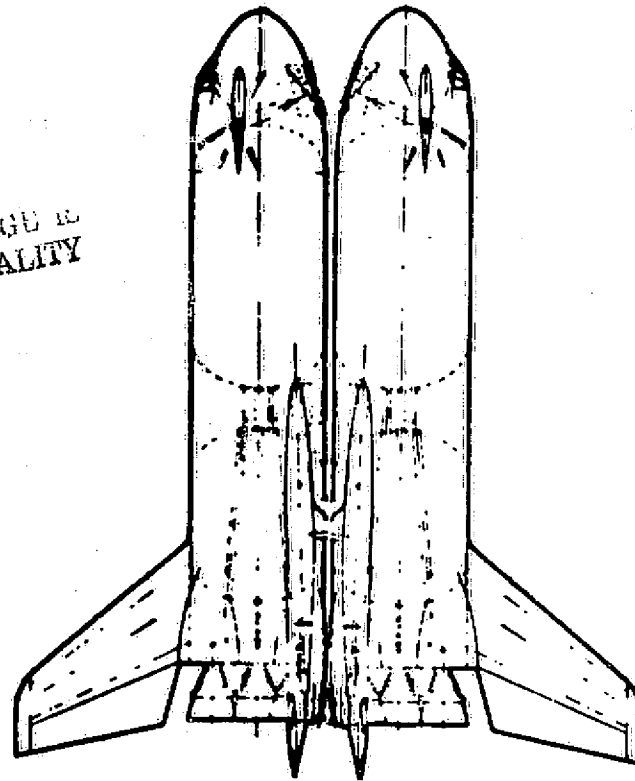
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PRELIMINARY HLLV CONCEPT

A potential HLLV candidate with equal size (volume) stages is depicted. The vehicle is a parallel burn configuration with propellant crossfeed from the 1st to 2nd stage and is capable of placing a 225×10^6 kg payload in an orbit of 500 km at an inclination of 28.5° . Both stages have fly-back capability; the 1st stage only employs air breathing engines. The boost phase uses LOX/RP in both stage engines. The 2nd stage employs multi-mode engines which operate on LOX/LH₂ during 2nd stage burn only. The configuration very nearly approximates a minimum glow vehicle for the prescribed payload.

PRELIMINARY VTO HLLV CONCEPT

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MASS PROPERTIES		
	10^6 KG	10^6 LB
GLOW	6.804	15.00
BLOW	5.443	12.00
WP ₁	4.627	10.20
U LOW	1.134	2.50
WP ₂	0.966	2.13
PAYLOAD	0.227	0.500

CONCEPT FEATURES

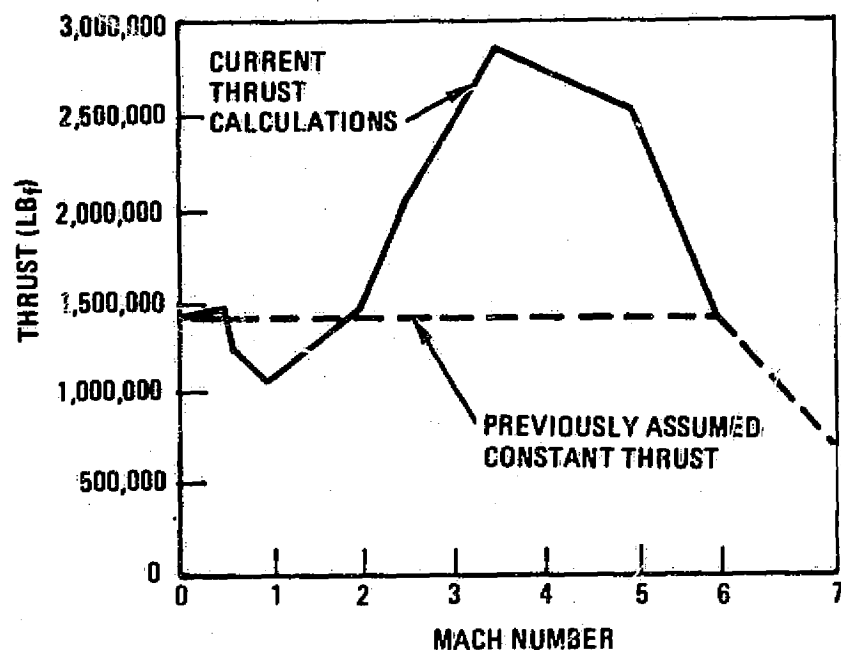
- LOX/RP 1ST STAGE
- LOX/RP - LOX/LH₂ (DUAL MODE) 2ND STAGE
- PROPELLANT CROSSFEED - PARALLEL BURN
- REGION OF MINIMUM GLOW
- STAGING VELOCITY 2377 M/SEC (7800 FT/SEC)
- STAGING ALTITUDE 61 KM (200,000 FT)



STAR-RAKER UPDATE

Revised performance for STAR-RAKER indicates a payload capability of approximately 200,000 lb to a 500 km, 28.5° inclined orbit when launched from KSC. The revised estimate of performance includes a 10% weight growth in vehicle structures and subsystems and is based on Rockwell estimates of RAM-JET performance. The primary difference between MSFC and Rockwell engine performance estimates is believed due to inlet area, pressure recovery and mainly that Rockwell uses a variable area nozzle where MSFC used a fixed area nozzle in their analyses.

STAR-RAKER UPDATE



*MASS PROPERTIES SUMMARY

AIRFRAME, AEROSURFACES, TANKS AND TPS	370,000
LANDING GEAR	27,700
ROCKET PROPULSION	71,700
AIRBREATHER PROPULSION	140,000
RCS PROPULSION	10,000
OMS PROPULSION	5,000
OTHER SYSTEMS	<u>37,800</u>
SUBTOTAL	662,200
10% GROWTH	<u>66,220</u>
TOTAL INERT WT	728,420
USEFUL LOAD (FLUIDS, RESERVES, ETC.)	<u>47,400</u>
INERT WT & USEFUL LOAD	775,820
PAYLOAD WEIGHT	<u>196,580</u>
ORBITAL INSERTION WT.	972,400
PROPELLANT ASCENT	<u>4,027,600</u>
GLOW (POST-JETTISON LAUNCH GEAR)	5,000,000

*300 N.MI., 28.5° INCLINED ORBIT



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SPS RESEARCH AND DEVELOPMENT PLANNING NETWORK

The probable inclusion of an extended Exploratory Research Program in SPS Development Planning, to evaluate microwave technical feasibility and environmental impact, needs to be evaluated at this point in time for its probable effect on overall development/verification planning options and time-lines.

The objectives of this reassessment are to synthesize all of the SPS projected research/development plans to date, including NASA 5 year plan multi-application enabling technology that will provide development support for the SPS system.

An underlying premise is that a heavily-funded dedicated SPS development effort in the next 5 years or so appears increasingly improbable. This leads to a planning logic that builds upon on-going and planned ground and space test activities that can result in SPS developmental progress if they can be appropriately torqued to achieve significant advancement of SPS technology, while also providing other planned benefits.

SPS RESEARCH AND DEVELOPMENT PLANNING NETWORK

OBJECTIVES

- ✓ ESTABLISH RELATIONSHIP OF EXPLORATORY RESEARCH PLAN TO OVERALL SPS VERIFICATION PLAN
- ✓ CATEGORIZE NASA AND DOE FUNDING AREAS
- ✓ SYNTHESIZE MSFC/JSC SPS PLANNING OPTIONS
- ✓ INTEGRATE
 - DOE ENVIRONMENTAL STUDIES
 - NASA LSS 5-YEAR PLANNING
 - SPS DEVELOPMENT PLANNING
- ✓ ESTABLISH MAJOR PLANNING MILESTONES FOR GROUND & SPACE TEST ACTIVITIES DEFINITION
- ✓ IDENTIFY & HIGHLIGHT SPS PLANNING ANOMALIES (I.E., LEO-LEO MW TEST VS. GRD-GEO MW TEST)



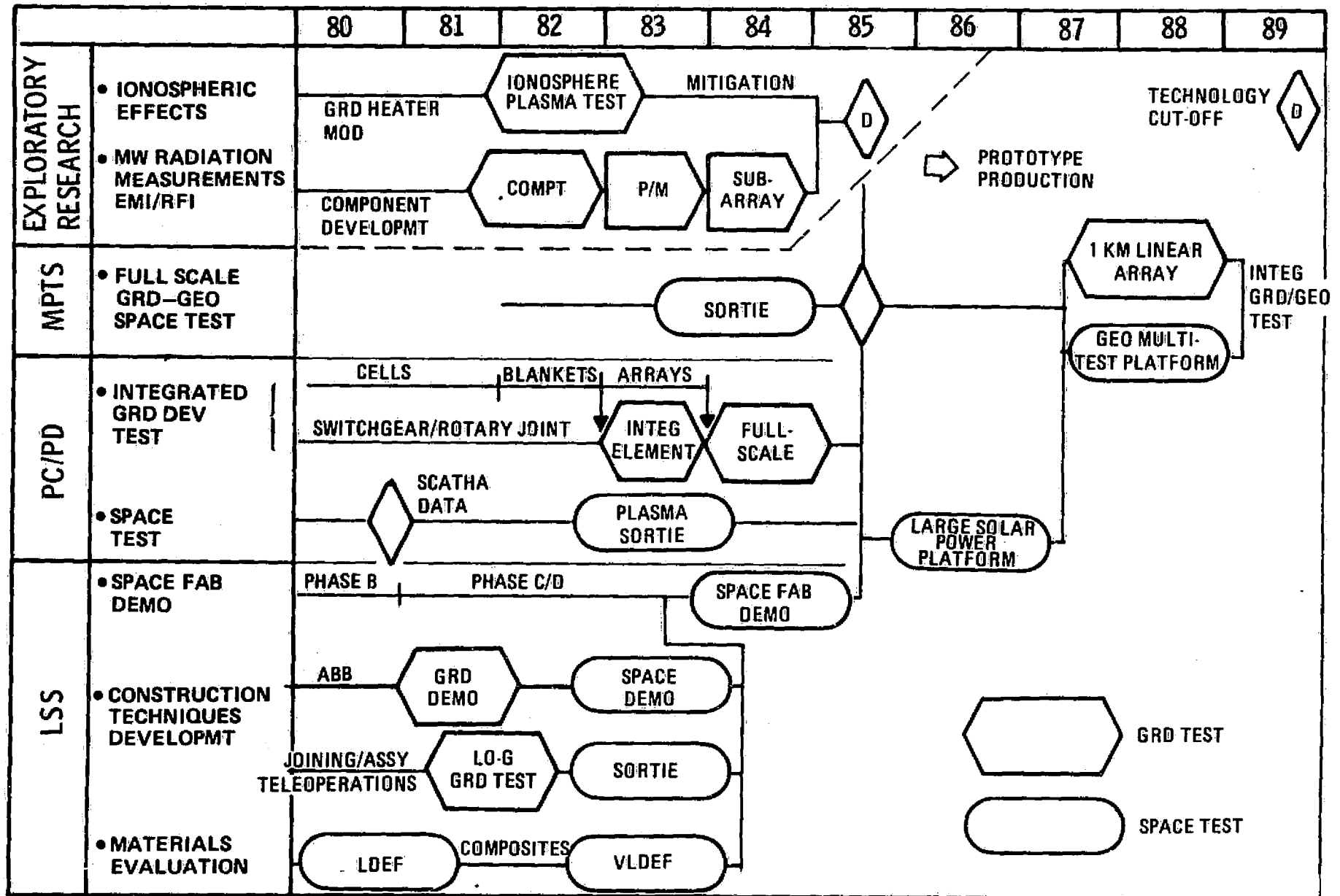
SPS PLANNING NETWORK OVERVIEW

A preliminary synthesis of the projected SPS development network is shown. The exploratory research plan segment is contained within the dashed lines and provides the "seed-bed" for prototype MPTS development.

Planned and on-going NASA enabling technology for power conversion/distribution and large space structures development are structured to provide evolutionary timelines leading to large SPS-type subscale space test articles during the end of the decade.

The commitment to large-scale SPS development ground and space test activity will come about 1985 based upon Exploratory Research Program results and will require funding levels on the order of several billions of dollars.

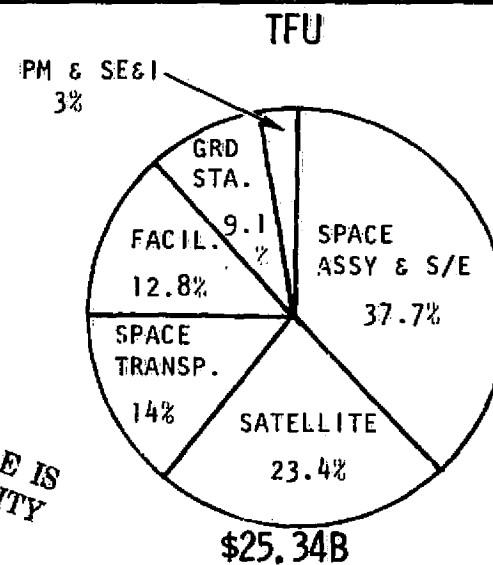
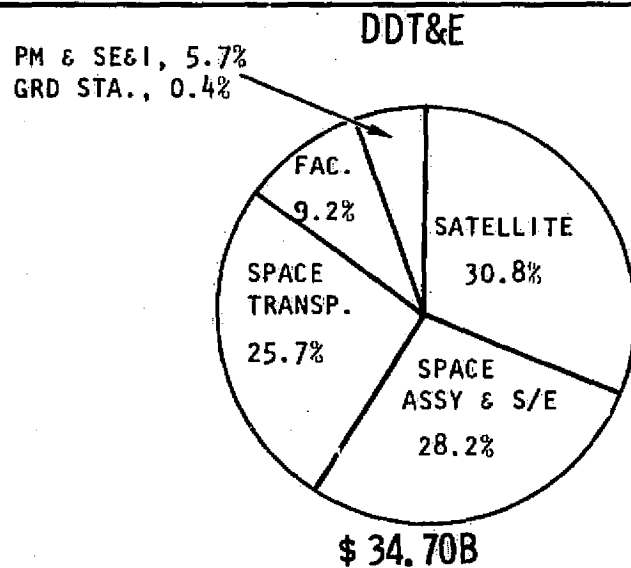
SPS PLANNING NETWORK OVERVIEW



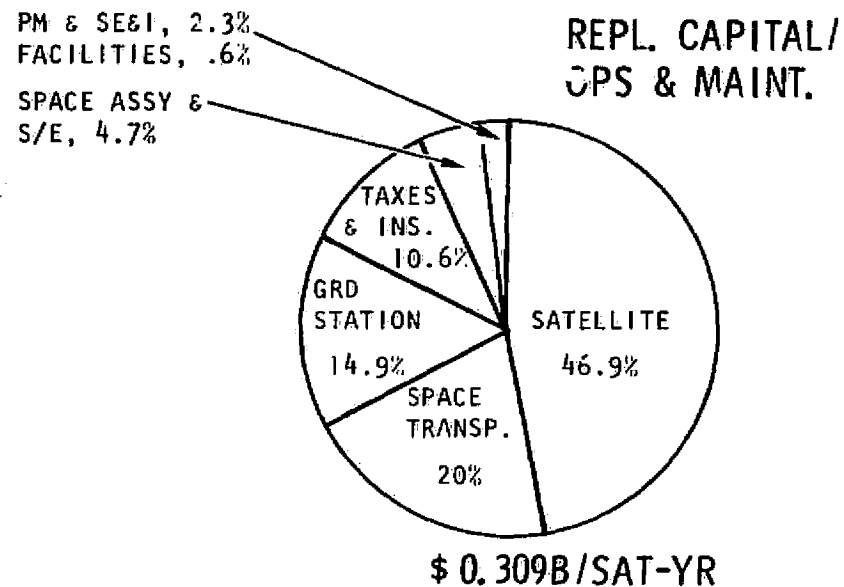
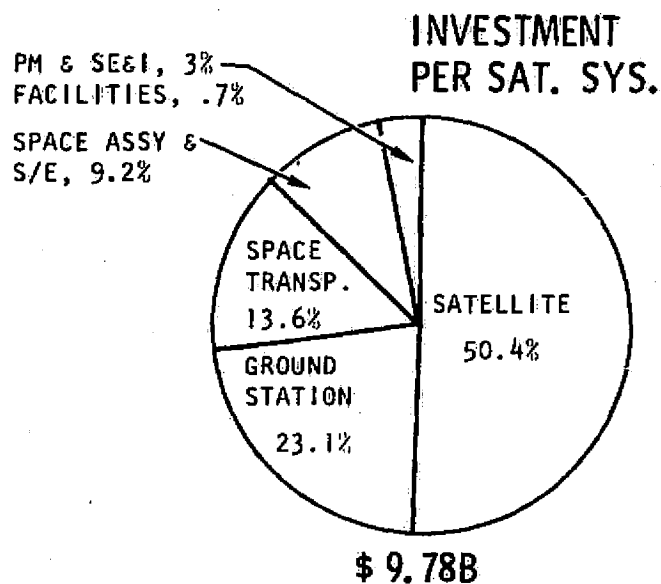
SPS COST BREAKDOWN

The relationship of cost estimates are shown for the DDT&E; theoretical first-unit (TFU); investment per satellite power system (average cost); and the operational costs (replacement capital/operations and maintenance). Total project development cost through the first full 5-GW satellite is \$60.0 billion. The average investment cost per satellite is based on an option of 120 systems over a 30 year period.

SPS COST BREAKDOWN



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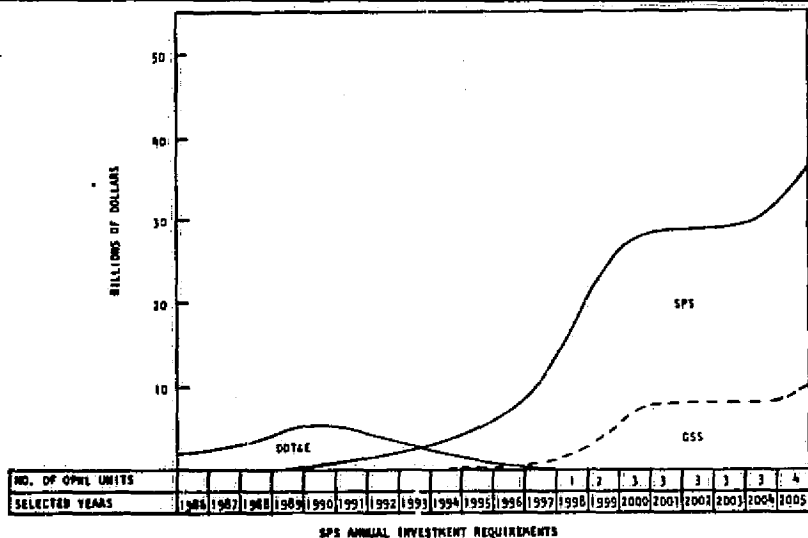
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SPS ECONOMICS

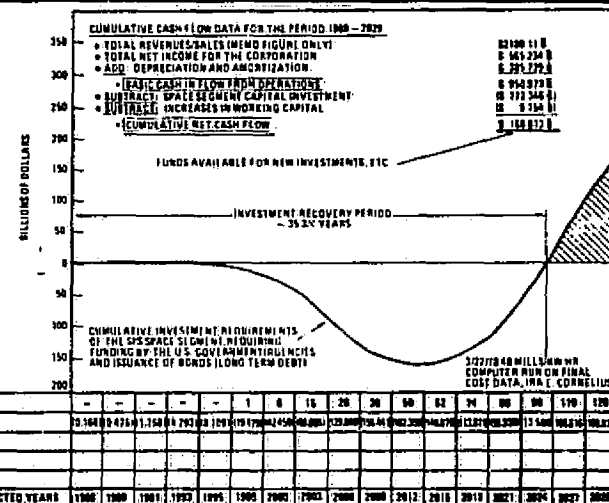
Annual SPS investments are illustrated with a comparison of DDT&E cost projections leading to an operational 5 GW satellite in 1998. The portion of SPS investment for the Ground Support System (GSS) - Rectenna are identified under the dashed lines.

Economic analyses established a total cumulative cash flow performance and investment recovery schedule for the (1) SPS Space Segment and (2) SPS Ground Segment in accordance with the Rockwell approach for an organizational structure and a method of financing the SPS. This chart shows the satisfactory investment recovery for the Space Segment and Ground Segment organizational entities based on 40 mills per kWh.

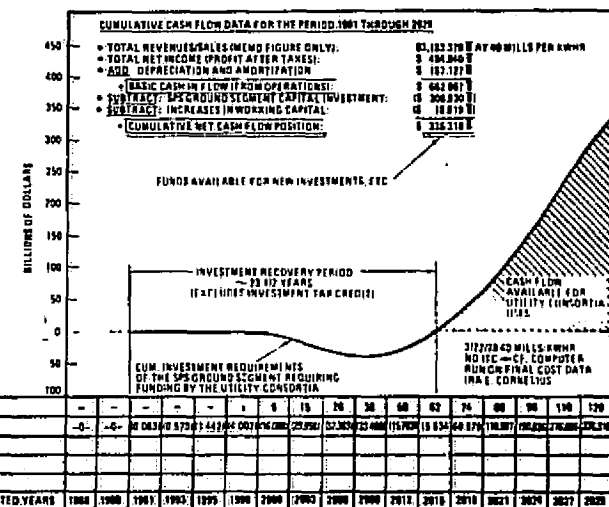
SPS ECONOMICS



SPS ANNUAL INVESTMENT REQUIREMENTS



NATIONAL BPS SPACE SEGMENT CORPORATION CONCEPT (FEDERALLY OWNED) - CUMULATIVE CASH FLOW & INVESTMENT RECOVERY SCHEDULE AT 10 MILLS PER KILOWATT HOUR



SPS GROUND SEGMENT UTILITY CONSORTIA CORPORATION CONCEPT - CUMULATIVE CASH FLOW & INVESTMENT RECOVERY SCHEDULE AT 40 MILLS PER KWHR (EXCLUDES INVESTMENT TAX CREDIT)

CONSUMER COST OF
40-MIL/KW-HR
RESULTS IN
GOOD ECONOMICS

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CONCLUSIONS

This chart is self-explanatory.

CONCLUSIONS

- CURRENT KLYSTRON DC-RF CONVERTERS STILL APPEAR TO BE BEST APPROACH
- SOLID-STATE MICROWAVE SPS WILL REQUIRE NEW SATELLITE CONCEPT
- CURRENT BASELINE CR-2 REFLECTOR APPROACH SHOULD BE RETAINED
- SSTD UPDATE INDICATES GREATER THRUST THAN PREVIOUSLY ASSUMED - 200 K LB PAYLOAD AT 28.5° INCLINATION
- SPS COST AND ECONOMICS INDICATE REASONABLE FINANCIAL CHARACTERISTICS WITH 40 MILL/KW-HR CONSUMER CHARGE



TASK 5 SYSTEM ENGINEERING/INTEGRATION STUDY LOGIC

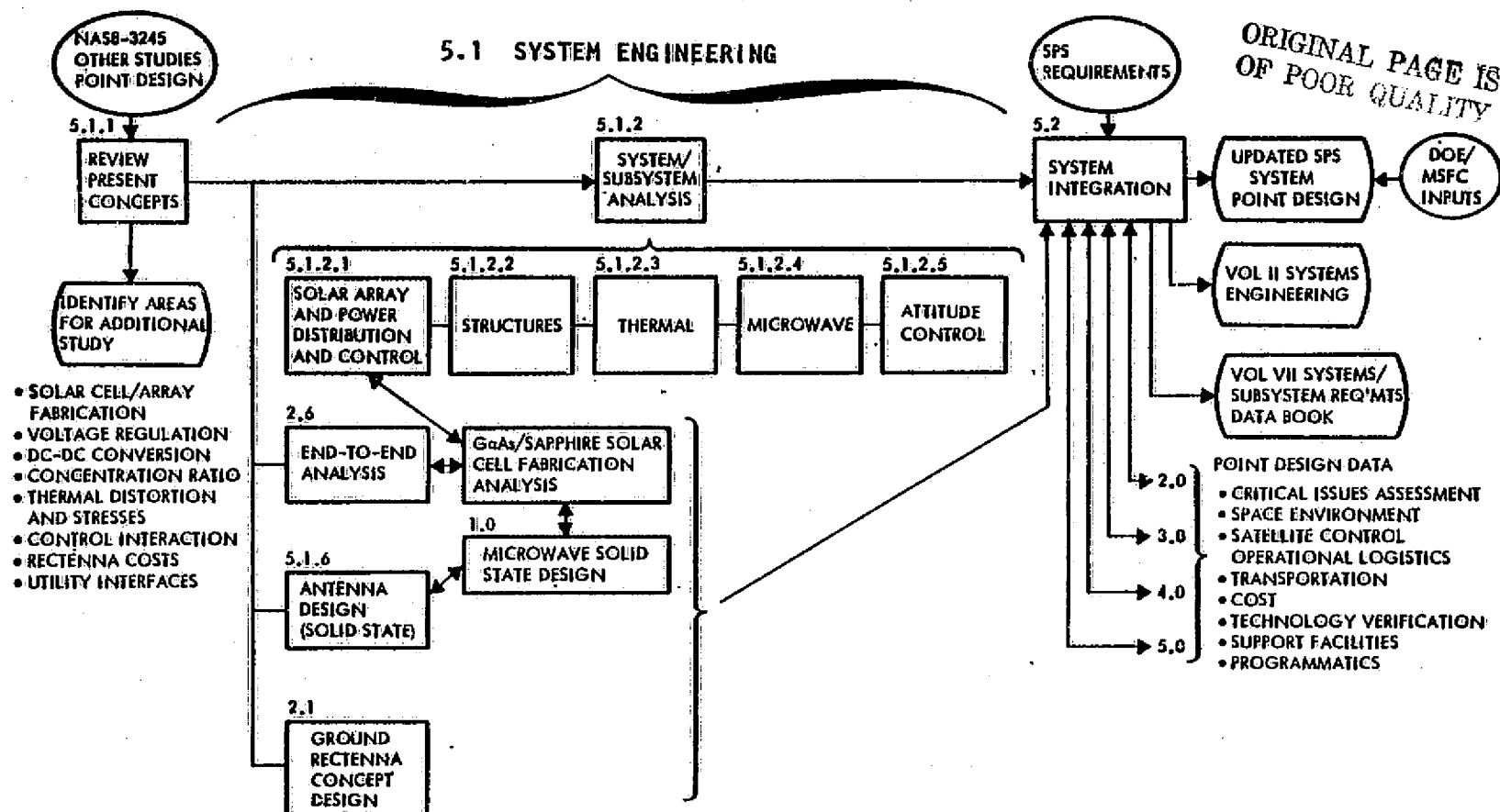
In Task 5, the data generated throughout the study and DOE/MSFC inputs will be used to update the present SPS system design concept. The logic diagram is shown; major subtasks are:

- 5.1 SPS Systems Engineering (space and ground elements)
- 5.2 SPS Systems Integration (space and ground elements)

System Engineering—This subtask re-evaluates the photovoltaic point design configuration on the basis of new data to improve the design configuration, and to resolve or reduce key areas of uncertainty in the concept. An updated satellite system concept will be prepared to support MSFC recommendations to HDQ/DOE. Revisions will be made after HDQ/DOE baseline decisions.

System Integration—This subtask is a major program activity necessary to establish a final revised and updated SPS system point design definition. The major output of this program activity is a set of summary requirements/point design documents describing the physical and performance characteristics of each of the elements making up the satellite system, and a detailed definition of its interfaces with transportation and support systems.

TASK 5 SYSTEM ENGINEERING/INTEGRATION STUDY LOGIC



REVIEW CURRENT SATELLITE DESIGN CONCEPTS

Some preliminary assessment of areas for further in-depth analysis were identified as indicated in the chart. A review of this was made, and the first-quarter study effort focused on the issues shown in the next two charts.

REVIEW CURRENT SATELLITE DESIGN CONCEPTS

SATELLITE ELEMENT	STUDY AREA		DATA TASKS	MAJOR IMPACTS
	MAJOR EMPHASIS	IN-DEPTH ANAL.		
SOLAR ARRAY	Solar cell performance	- Cascaded solar cells - Environment model	5.1.2 2.4	Mass and cost
	SOL excess power	- On-array regulation - Satellite/rectenna sizing - Storage	5.1.2 5.1.2, 5.1.3, 2.1 2.6	Cost and design simplicity
	Solar cell fabrication	- Blanket/interconnects (module design) - Solar cell cross-section	2.2, 2.6, 5.1.2	Cost and design simplicity
	Concentration ratio	Reflector slant angle	5.1.2	Cost, mass, design simplicity, and resources
	EOL reflectivity	- Environment model - Test results	2.4 5.1.2	Cost and mass
POWER DISTRIBUTION	Voltage requirements	- DC-dc converters - Redundancy reqmts - Regulation	5.1.2, 5.1.3 2.6 5.1.2	Cost, mass, design simplicity
	Conductor lines	Routing and installation (antenna, rectenna switching and circuit protection)	5.1.2, 2.1, 2.2	Cost, mass, design simplicity and safety
	Power transfer across rotary joint	Slip ring/brush design	5.1.2, 2.2	
STRUCTURES	Material thickness requirements	- Thermal environ. - Load conditions - Stresses	5.1.2	
	Rotary joint	- Rotary joint dia. - Technology reqmts.	5.1.2	
THERMAL CONTROL	Temperature profiles (heat loads)	- Structure - Rectenna - Antenna	5.1.2 5.1.2, 2.1 5.1.2, 5.1.3	
	Operational scenarios	Thermal impact (construction base, assy, transp., orbit transfer, etc.)		
MICROWAVE	RF to dc converters	- Module design - Materials - Power distribution		
	Early technology verification	Line source fan-beam pattern		

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ASSESS CURRENT DESIGNS
AND IDENTIFY AREAS FOR
FURTHER STUDY → UPDATE
SPS POINT DESIGN



SYSTEM STUDIES

A review of the current design was made and areas identified for further study. This chart summarizes some preliminary assessments of areas for further analysis. Major impacts for concern were cost, mass, and design complexity. Primary emphasis was on reducing overall cost.

SYSTEM STUDIES

SUBSYSTEM/ELEMENT	ANALYSIS/TRADE	MAJOR IMPACT/CONSIDERATION
SOLAR ARRAY	● SOLAR CELL PERFORMANCE ● B.O.L. POWER ● SOLAR CELL COST ● E.O.L. REFLECTIVITY ● CONCENTRATION RATIO ● EARLY VERIFICATION	● GaAs SINGLE CRYSTAL CELL STILL PREFERRED ➤ BEST FOR FUTURE MAY BE GaAs MULTIPLE BAND GAP POLYCRYSTALLINE ● EXCESS SOLAR ARRAY POWER SHOULD BE UTILIZED ~297 MW (AVG), 490 MW (PEAK) ● GROUND STORAGE LOOKS MARGINAL ● E.O.L. REFLECTIVITY INCREASED FROM 0.72 TO 0.83 ~500 MW GAIN ● STAY WITH 60° SLANT ANGLE ● CR=2 OFFERS COST ADVANTAGE
POWER DISTRIBUTION	● EFFICIENCY CHAIN ● LOW VOLTAGE REQMT ● BLOCK DIAGRAMS & POWER CONTROL ANALYSIS	● ηO.A. REDUCED FROM 6.06% TO 5.78% ● VERY DIFFICULT TO PROVIDE 40 KV TO 40 VDC (SOLID STATE) ~0.5-1 KG/KW ● INITIAL INTERFACES; START OF INTEGRATED BLOCK DIAGRAM
STRUCTURES	● NASTRAN ANALYSIS	● INCREASED NUMBER OF BRACES FOR STABILITY ● PRELIMINARY STRESS ANALYSIS DESIGN LOOKS O.K.



SYSTEM STUDIES (CONTINUED)

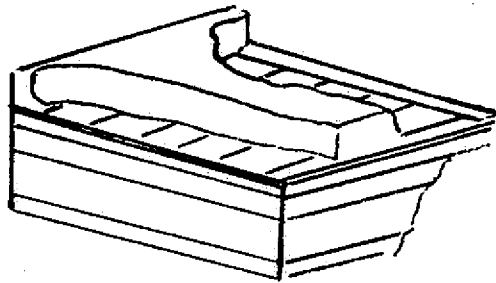
SUBSYSTEM/ELEMENT	ANALYSIS/TRADE	MAJOR IMPACT/CONSIDERATION
THERMAL	● POWER CONDITIONING COMPONENT ANALYSIS ● SOLID STATE DEVICE ANALYSIS	● THERMAL CONTROL RADIATORS FOR VOLTAGE CONVERTERS ~ 10⁶ KG MASS INCREASE ● THERMAL CONTROL CONCEPT FOR TRANSISTOR POWER MODULES ~2X DEVICE WEIGHT
ANTENNA	● SOLID STATE DC/RF CONVERSION	● 50 KW SOLID STATE POWER MODULE CONCEPT ● EFFICIENCY DC-RF 78-85% WAS 85%; POWER DISTRIB. 80-95% WAS 96%
RECTENNA	● STRIP LINE VS "BACKFIRE" COAXIAL ● UTILITY INTERFACE AC VS DC ● DC TO AC CONVERSION CONCENTRATED VS DISTRIBUTED	● STAY WITH STRIP LINE ● AC FOR < 300 MILES; DC FOR > 800 MILES ● CONTROLLED QUASI-SINEWAVE DEVELOPED FROM RECTENNA ARRAY SEGMENTS LOOKS ATTRACTIVE (DISTRIBUTED CONCEPT).



CONFIGURATION

This chart depicts three solar cell configurations used in a comparison study of GaAlAs, single crystal silicon and amorphous silicon to assess relative advantages/disadvantages of amorphous silicon. The current GaAlAs solar cell configuration was utilized as shown in the chart at a mass of 0.252 kg/m^2 . The single crystal silicon solar cell stack configuration was modeled from the NASA/JSC SPS study. Amorphous silicon configuration was modeled from an RCA paper presented at the 12th Solar Photovoltaic Specialist Conference. It was assumed that A-silicon cell stack weight is equivalent to 1 mil of glass mounted on the blanket configuration as utilized in the GaAlAs case. A concentration ratio of 1 was used.

CONFIGURATION



GaAs

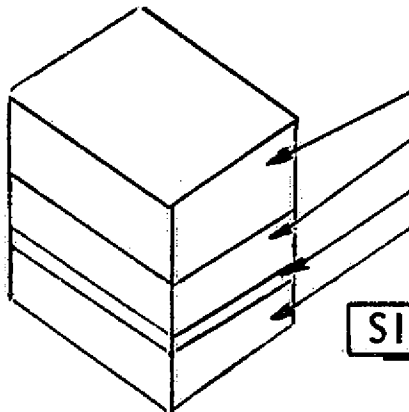
BLANKET DESCRIPTION

20 μm Al_2O_3		MASS
INTERCONNECTS & GRID CONTACTS		7.96
.03-.05 μm GaAs		3.4
1.5 μm P-TYPE GaAs	} 5 μm	.03
4-6 μm N-TYPE GaAs		2.66
.5-1 μm OHMS CONTACTS		4.0
13 μm FEP		2.7
25 μm KAPTON		3.6
6-12 μm POLYMER THIN COATING		.0.9

25.25 MG/CM²

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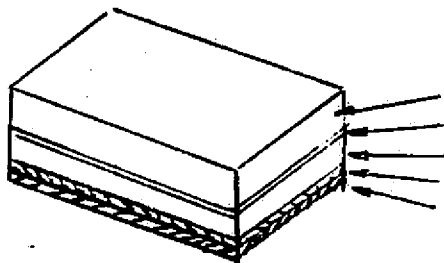
0.252 kg/m²



3 MIL SILICA
2 MIL SILICON
1/2 MIL INTERCONNECTS
2 MIL SILICA

SINGLE CRYSTAL SILICON

0.426 kg/m²



GLASS (~25 μm)
PT
UNDOPED a-Si (~1 μm)
n + a-Si o
CR (~1000 Å)

AMORPHOUS SILICON

0.143 kg/m² *

*ASSUMES GaAs BLANKET CONFIGURATION



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PERFORMANCE

The relative performance and cost model for the three solar cell configurations used in the study are shown in this chart. Present status on the amorphous silicon is about 5.5% efficiency. For the study, parametric values of efficiency ranging from 10% to 14% were used. (NOTE: The theoretical efficiency of A-silicon is about 15%.) A cost analysis based on materials cost, cell manufacturing process costs, and blanket manufacturing process costs was performed for the three configurations. The results are presented in the chart. (NOTE: Process costs are held the same for all three configurations.) The A-silicon cell process cost is expected to be lower. This effect is shown in a later chart.

PERFORMANCE

PARAMETER	SUMMER SOLSTICE		
	GaAs	SILICON	A-SILICON
ENERGY ONTO CELL	1319.5 W/m ²	1319.5 W/m ²	1319.5 W/m ²
CONVERSION EFFICIENCY	20%	17.33%	10% → 14%
PWR OUTPUT f(T)	(1.0) 263.6 W/m ²	(.954) 218.11	(.954) 125.9 → 176.2
ARRAY DESIGN FACTOR (.89)	234.8	194.1	112.1 → 156.8
SEASONAL VARIATION .91)	213.7	176.6	101.9 → 142.7
ENVIR. DEGRAD.	(.96) 205.2	(.85) 150.1	(.85) 86.6 → 121.2

() = PERFORMANCE DEGRADATION FACTOR

NOTE: AMORPHOUS SILICON THEORETICAL EFFICIENCY ~15%

COST MODEL

SOLAR CELL CONFIGURATION	CELL/BLANKET MAT'L \$/m ²	CELL PROCESS \$/m ²	BLANKET PROCESS \$/m ²	TOTAL \$/m ²
GaAs/Al ₂ O ₃	36.815	17.00	17.00	70.815
SILICON	13.251	17.00	17.00	47.251
A-SILICON	3.096	17.00	17.00	37.096

MATERIAL COSTS:

GALLIUM	-	\$500/kg
As	-	150/kg
SAPPHIRE	-	325/kg
SILICON	-	60/kg
OTHERS	-	20/kg



MASS

The effect on mass for design and integration penalties are shown in the chart. The greatest mass penalty (18.659×10^6 kg) is with the single crystal silicon due to its heavier cross-section. The penalty for A-silicon varies from 13.81×10^6 kg to 4.585×10^6 kg, depending upon its efficiency. The GaAlAs design is used as a reference for comparison. The major weight impact is from solar cell and structural considerations due to change in solar array requirements.

MASS

SOLAR CELL CONFIGURATION	ARRAY		Δ STRUCTURE (10^6 kg)	Δ PDC (10^6 kg)	TOTAL Δ MASS (10^6 kg)
	AREA (10^6m^2)	MASS (10^6 kg)			
GaAlAs/ Al_2O_3	49.96	(12.59)	(5.28)	(1.845)	(19.215)
SILICON	68.27	+16.507	+1.64	+0.512	+18.659
A-SILICON 10%	118.4	+4.34	+6.139	+3.33	+13.81
12%	98.65	+1.51	+4.367	+2.507	+8.38
14%	84.55	-0.5	+3.10	+1.985	+4.585

NOTES

() = REFERENCE MASS

STRUCTURAL MASS PENALTY = 0.087 kg/m^2 (SA)

PDC " " = $\left(\frac{A_1}{A}\right)^2$ MAIN FEEDERS

= $\left(\frac{A_1}{A}\right)$ REMAINDER



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COST SUMMARY

The effect of design and integration penalties on cost is shown for the three solar cell configurations. The delta costs include solar cell, transportation, structure, and power distribution control. The major impacts are solar cell, transportation, and structure cost deltas. The silicon single crystal solar cell shows a savings in cell cost of \$312.1 million matched against increased transportation, structures, and PDC costs. A delta cost increase of \$526.7 million is attributed to this configuration. The GaAlAs solar cell costs are shown for reference. Amorphous silicon starts to look competitive at the higher efficiency; e.g., 14% efficiency shows a delta cost increase of \$214.25 million. The cost model used in this exercise is shown in the chart for TFU. This represents an increase of approximately 22.5% above average unit costs over the total SPS program. These costs were taken from Exhibit A/B study results.

COST SUMMARY

COST PARAMETER	GaAs	SILICON	A-SILICON		
			10%	12%	14%
SOLAR CELL COST	- (3.5379B)	-312.1M	+843M	+113M	-240.9M
TRANSPORTATION	- (739.31 M)	+699.71M	+517.87M	+314.25M	+171.93M
STRUCTURE	- (425.88 M)	+132.28M	+495.17M	+352.24M	+250.05M
PDC	- (28.05 M)	+6.37M	41.75M	34.41M	33.17M
SUBTOTALS	- (4.731 B)	+526.76M	+1897.79M	+813.9M	+214.25M
30% GROWTH	-	158.028M	569.34M	244.17M	64.28M
TOTAL	-	+684.79M	2467.13M	1058.07M	278.53M

COST MODEL (TFU)

TRANSPORTATION TO GEO = \$37.5/kg
 STRUCTURES = \$80.66/kg
 CONDUCTORS = 1.52/kg
 SWITCH GEAR = 65/kg



CONCENTRATION RATIO COMPARISON--DELTA COST

The previous charts dealt with comparisons at a concentration ratio of 1. The baseline configuration is designed for CR = 2. This chart shows a cost comparison of GaAs CR = 2 (baseline) with silicon (CR = 1) and GaAs (CR = 1). Significant differences are identified with the major impacts coming from difference in solar cell performance and specific cell stack weights. The silicon CR = 1 shows a cost penalty of 2126.73 ¢ and GaAs CR = 1 a penalty of 1572.88 ¢. The cost technique utilized was similar to that outlined in the previous charts.

CONCENTRATION RATIO COMPARISON ~ DELTA COSTS

PARAMETER	DELTA COST		
	GaAs CR=2	SILICON CR=1	GaAs CR=1
SOLAR CELL COST	(2320 $\bar{M}$)	961 $\bar{M}$	1274.6 $\bar{M}$
TRANSPORTATION	(507.75 $\bar{M}$)	935.4 $\bar{M}$	211.5 $\bar{M}$
STRUCTURE	(285.51 $\bar{M}$)	208.1 $\bar{M}$	75.58 $\bar{M}$
PDC	(16.91 $\bar{M}$)	19.5 $\bar{M}$	11.2 $\bar{M}$
SUBTOTAL	(3130.2 $\bar{M}$)	2126.73	1572.88 $\bar{M}$
GROWTH 30%	(939.1 $\bar{M}$)	638.01	471.86
TOTAL	(4069.3 $\bar{M}$)	2764.75 $\bar{M}$	1944.74 $\bar{M}$

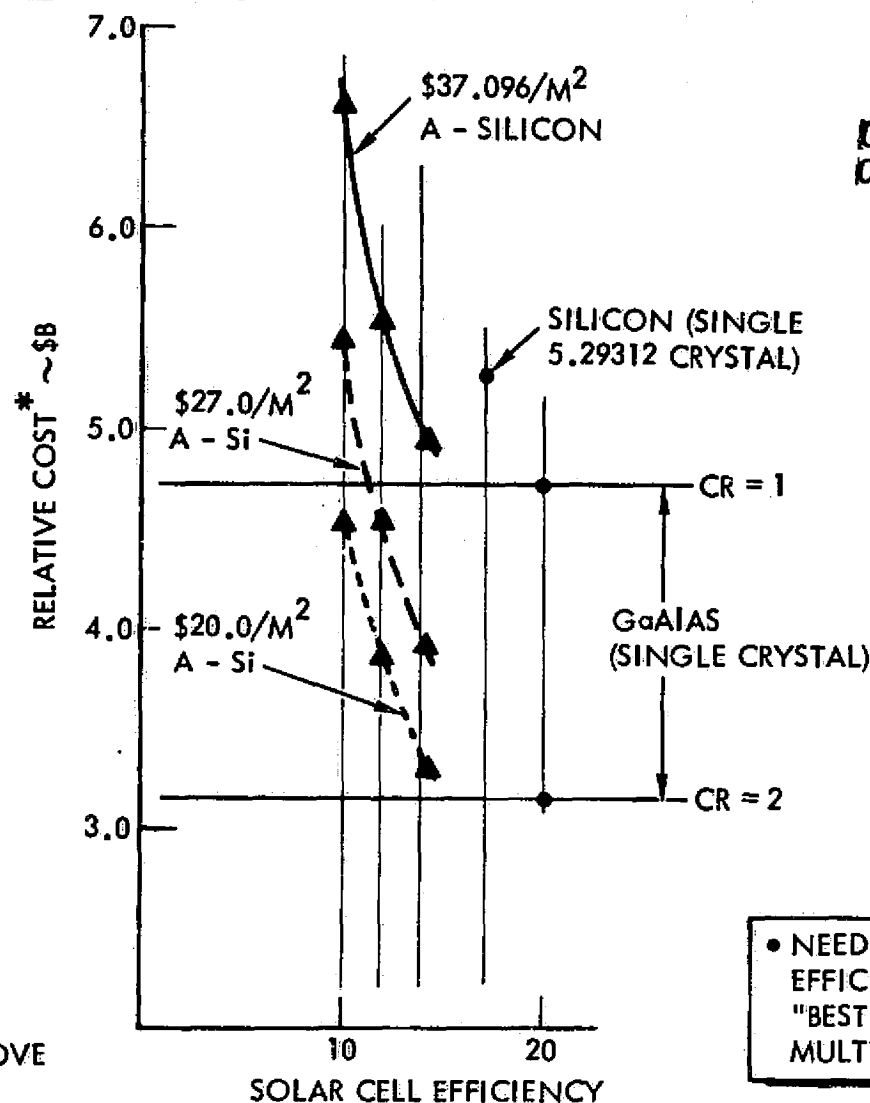
() = REFERENCE COST



SOLAR ARRAY COST COMPARISONS

This chart shows a parametric cost comparison between fixed design costs for silicon (CR = 1), GaAs CR = 1 and CR = 2, and amorphous silicon varying in efficiency from 10 to 14 percent. As shown, the A-silicon must achieve both low cost (~\$20.0/m²) and high efficiency (14%) to approach the GaAs CR = 2 baseline.

SOLAR ARRAY COST COMPARISONS



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- *COSTS INCLUDE
- SOLAR CELLS/ARRAYS
 - STRUCTURE
 - PDC
 - PLUS TRANST. ON ABOVE

- NEED LOW COST & HIGH EFFICIENCY
- "BEST BET" - POLYCRYSTALLINE MULTI-BAND GAP GAALAS



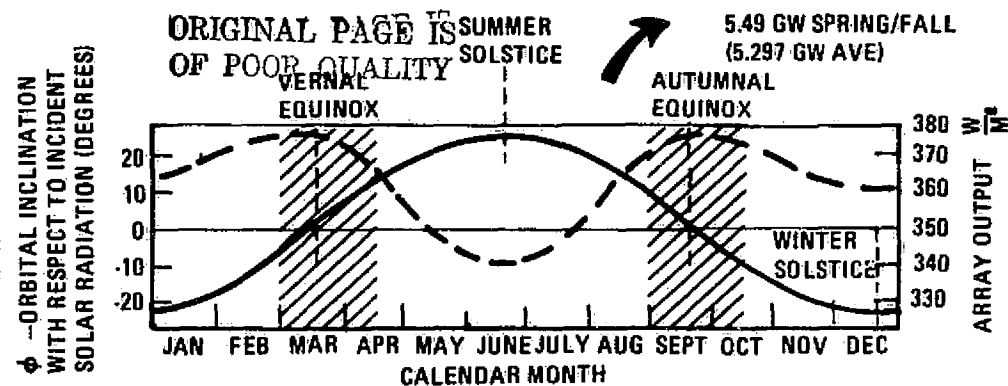
SEASONAL VARIATIONS IN AVAILABLE POWER

This chart shows available power values as a function of season. As indicated, approximately 10% additional power is available from the solar array spring and fall equinox, as compared to the summer solstice (point design). This is due to variations in the angle of inclination and solar constant. A profile of the ecliptic duration is shown.

Performance of the solar array is based on a nominal GaAs solar cell efficiency of 20%. Science Center has shown performance values (best data) to indicate a cell efficiency of 22.1%.

SEASONAL VARIATIONS IN AVAILABLE POWER

	SPRING/FALL EQUINOX	SUMMER SOLSTICE	WINTER SOLSTICE
CR _G	2.0		
SOLAR INPUT	1360.8 W/M ²	1319.5	1402.0
CR (EFF.) 1.83			
ENERGY ONTO CELL	2490.3 W/M ²	2414.7	2565.7
TEMP. °C	125	113	119
CONV. EFF. f(T)	.176	.1816	.179
ENERGY CONVERTED	438.3 W/M ²	438.5	459.3
ARRAY DESIGN FACTOR (.89)	390.087	390.265	408.78
SEASONAL VARIATION (.91)		355.14	371.99
ENVIR. DEGRAD. (.96)	374.48	340.94	357.11

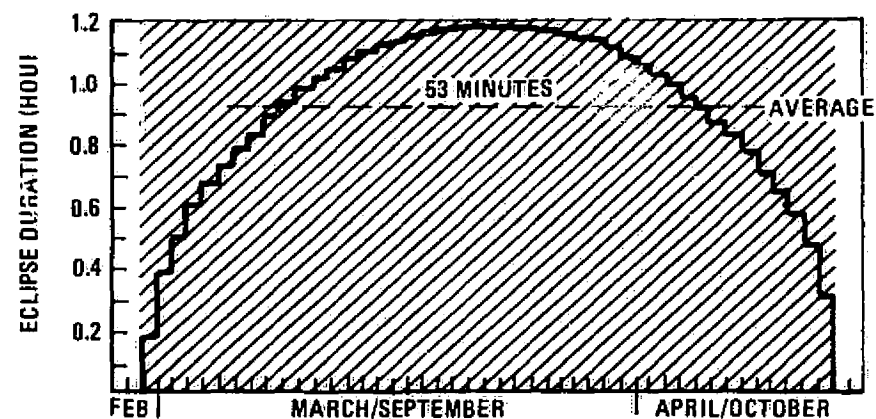


CELL EFFICIENCY

$$= \frac{I_{SC} V_{OC} F.F.}{S}$$

BEST DATA OBTAINED TO DATE (GAAS)*	
I _{SC}	34 MA/CM ²
V _{OC}	1.0 VOLTS
F.F.	0.88
CALC	22.1%

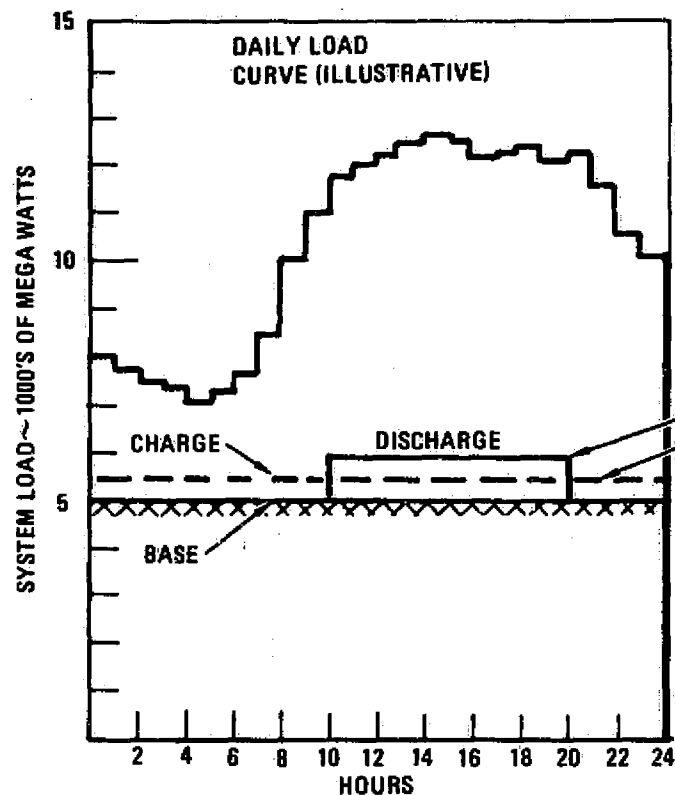
*ROCKWELL SCIENCE CENTER DIVISION



COST OF GROUND STORAGE

To utilize excess solar array power, there are two options identified: (1) size the satellite to deliver on a continuous basis the excess power to the utility grid, and (2) include a ground storage system and deliver the excess power from storage during peak demand periods. The SPS baseline could provide 5.5 GW (maximum) or 5.297 (average) because of seasonal variations. The chart shows energy storage capital costs for different storage techniques.

COST OF GROUND STORAGE



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COMPRESSED AIR ENERGY STORAGE⁽¹⁾

ANNUAL DUTY ~ 2000 HOURS
GEN. PER DAY ~ 10 HRS
PWR GEN. CAP. ~ 800 MW

EQUIPMENT	CAPITAL \$	\$/KWE
AIR STORAGE SYSTEM	14.2 M	17.75
TURBO MACHINERY	90.4 M	112.5
ELECT. EQMT	6.6 M	8.25
STRUCTURES	2.8 M	3.5
INDIRECT COST	17.0 M	21.25
CONTINGENCY	27.0 M	33.75
TOTAL	158.0 M	197.5

19.75/KWH
OPS COST ≥ 1 CENT/KWH

ALTERNATIVES:	\$/KWE	LIFE	OPS COST
PUMPED HYDRO	150-200	50 YRS	0.1 CENTS/KWH
BATTERIES	50-100	10-20 YRS	0.1 CENTS/KWH
	+ 25-30/KWH		
ELECTROLYSIS/FC	30-75	20 YRS	0.1 CENTS/KWH
	+ 20/KWH		

- YEARLY REVENUE POT.: AT \$.05/KWH (75% C/D EFF.)

1934 GWH → = \$96.7 M/YR
YR

- ECLIPSE SEASON (ONLY):

764 GWH → = \$38.2 M/YR
YR

(1) REFERENCE:
12TH IECEC



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COST OF EXCESS POWER

This chart itemizes the satellite penalties associated with utilizing excess solar array energy. The cost values shown indicate a cost-effective impact by utilizing the excess energy. Lower cost per satellite might be achieved since the delta cost per kilowatt is lower than the base SPS costs. The conclusion reached from this analysis is that the SPS design criteria should be revised to include utilization of excess solar array power.

COST OF EXCESS POWER

		<u>Δ MASS (10⁶ KG)</u>	
<u>COLLECTOR ARRAY</u>			
STRUCT. & MECH.	(3.777)	N/C	
ATT. CONT.	(.095)	N/C	
POWER SOURCE	(8.831)	N/C	
POWER DISTR.			
CONDIT.	(.259)	0.0259	} ~0.5% ADDED LINE LOSS
CONDUCT.	(.699)	N/C	
SLIP RINGS	(.208)	N/C	
IMS	(.050)	N/C	
<u>ANTENNA SECTION</u>			
STRUCT. & MECH.	(1.685)	N/C	
THERMAL CONT.			
KLYSTRON COOL.	(.851)	.0851	
INSULATION	(.557)	.0557	
MICROWAVE PWR			
KLYSTRONS	(4.25)	.425	
ELECTRONICS	(.142)	N/C	
WAVEGUIDES	(2.62)	.262	
POWER DIST.			
CONDIT.	(1.635)	.1635	
DISTR.	(1.834)	N/C	
IMS	(.630)	N/C	
SUBTOTAL	(28.123)	1.0152	
30% GROWTH	8.437	.3046	
TOTAL	36.560	1.3198	

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\$ TFU	Δ COST
TRANSP. @ \$37.5/KG =	49.5 M
POWER COND. @ \$65.6/KG =	12.42 M
HT. PIPES @ \$4.21/kg =	.59 M
KLYSTRONS/WAVEGUIDES @ \$284/KG=	195.1 M
SUBTOTAL Δ'S =	257.62 M
<u>RECTENNA</u>	
DIPOLE @ PWR RATIO =	94.45 M
PDC @ PWR RATIO =	5.11 M
SUPPORT STRUCT. PWR RATIO =	69.51 M
TOTAL Δ'S	426.69 M

$$\frac{426.69 \text{ M}}{297 \text{ MW}} \sim \$1378/\text{KW}_e(\text{TFU}) \times .861 = \$1186.5/\text{KW}_e (\text{AVG})$$

IMPACT (POTENTIAL)

- REDUCES INV. PER SAT. BY \$47.3/KW_e
- REDUCES TOTAL NO. SPS'S BY ~7

$$\frac{600 \text{ GW}}{5.297 \text{ GW SPS}} \sim 113.3 \text{ SATELLITES}$$

- ✓ • FUTURE DESIGNS SHOULD UTILIZE EXCESS POWER
 - GROUND STORAGE PROBABLY MARGINAL



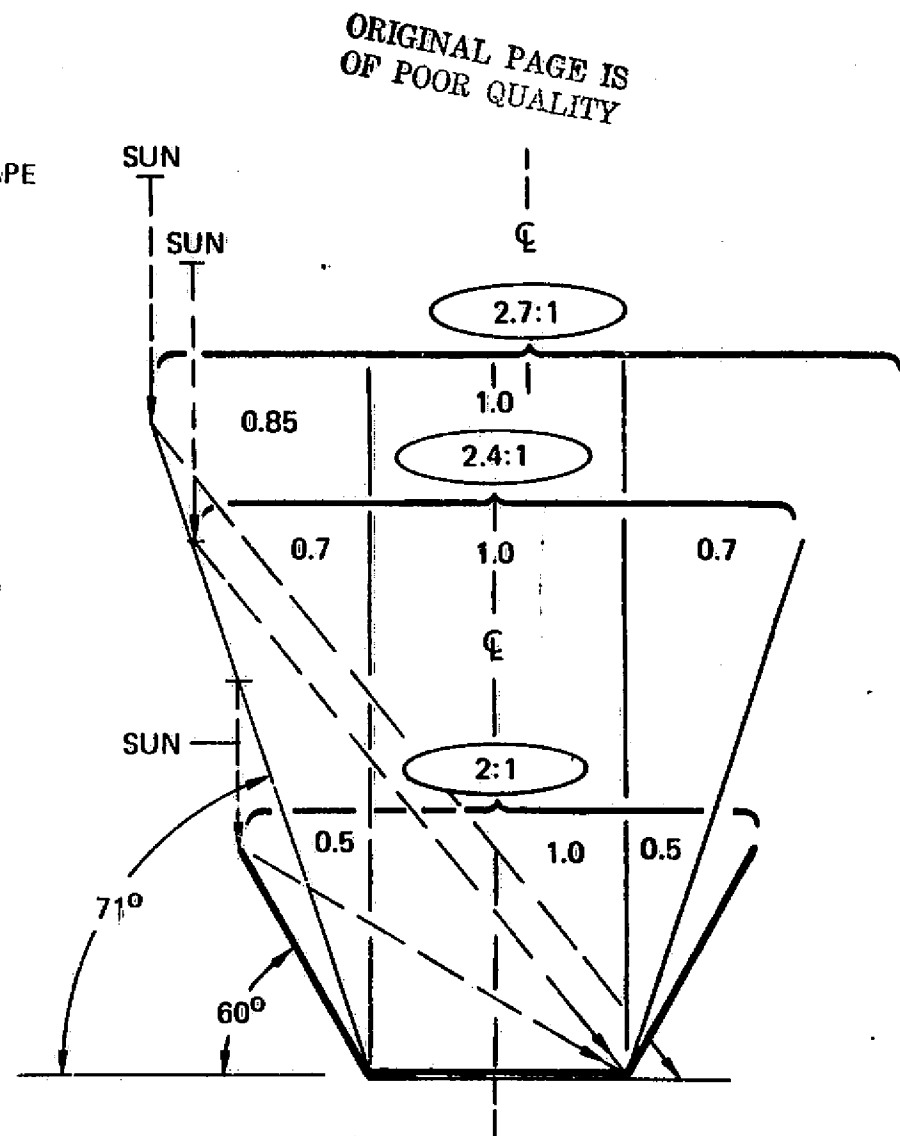
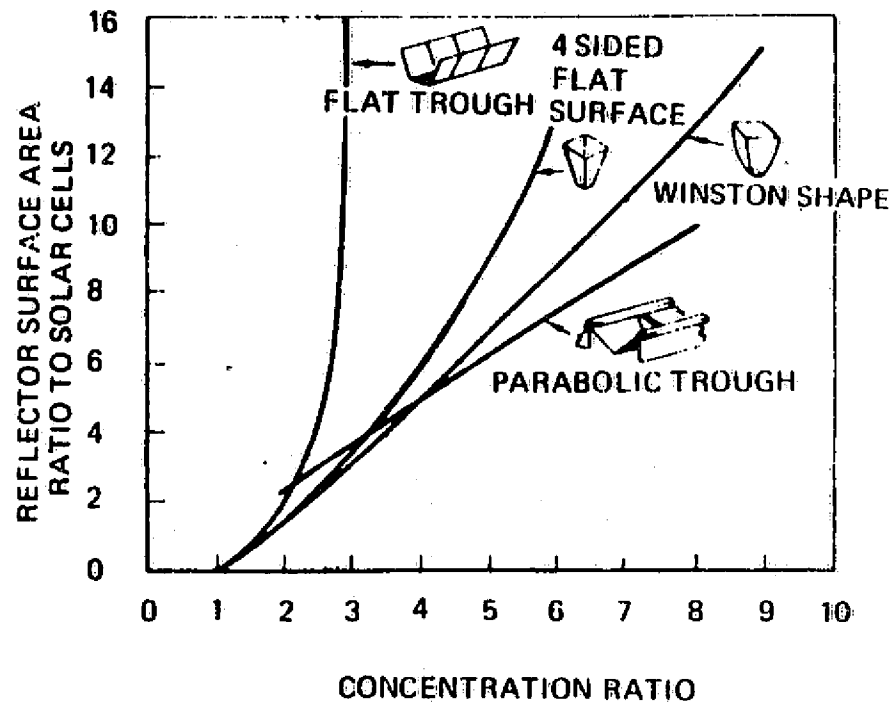
REFLECTOR SHAPE

A summary of the design concepts that were given final consideration for selecting a point design concept is shown in these charts. The concentration ratios, reflector shape and angle, area requirements, and subsystem weights are presented for the configurations. The selected design concept for the point design is the 60° Vee-trough configuration. It was felt that an advantage might be realized by a higher slant angle.

The geometry and ray traces for the Vee-trough design for a 60° and 71° reflector slant angle are shown. As illustrated, for a CR = 2 the slant angle is 60°, and for a CR = 2.4 the reflector slant angle is 71°.

The following charts show results of a trade comparison of slant angle. Considerations are given to weight, cost, on-orbit assembly, and fabrication and design complexity.

REFLECTOR SHAPE

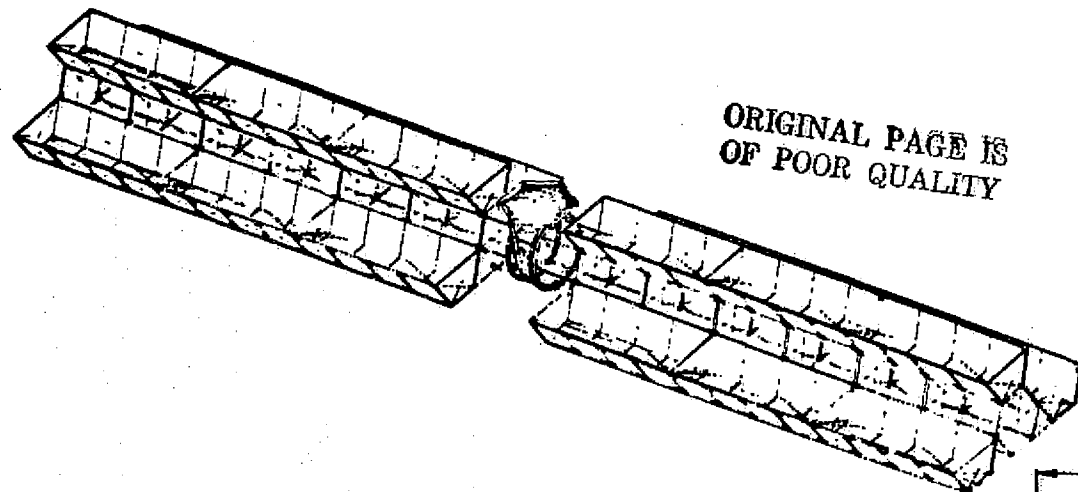


SPS STRUCTURAL CROSS-SECTION, 60°, 3-TROUGH

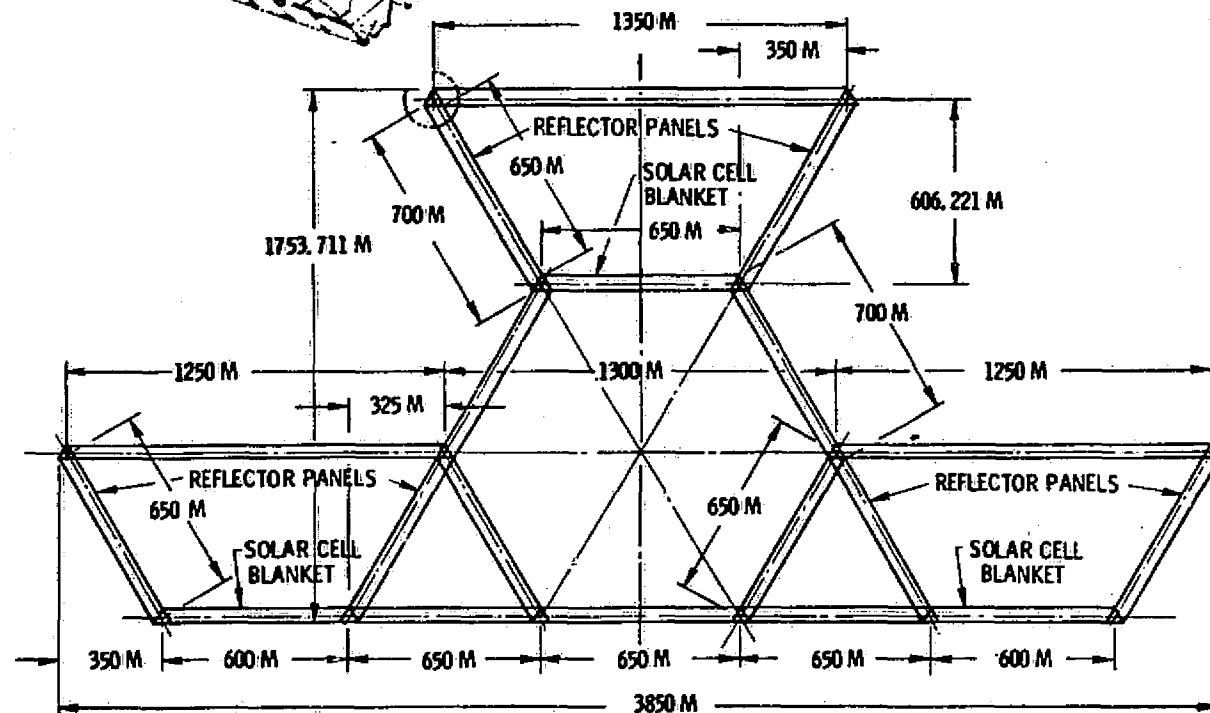
This chart shows the SPS structural cross-section for the baseline photovoltaic configuration. This configuration is used to model the 60-degree (three troughs) reflectors using a 650-meter radius rotary joint.

The following three charts depict various other slant-angle configurations used in the comparison.

SPS STRUCTURAL CROSS SECTION (60°, 3 TROUGH)



- SAT. LENGTH = 20.9 KM
- CROSS SECTION
BEAM LENGTH = 11.1 KM
- CRGEOM. = 2.0
- SOLAR CELLS = $30.06 (10^6) \text{ M}^2$
- REFLECTOR SURFACE = $60.12 (10^6) \text{ M}^2$

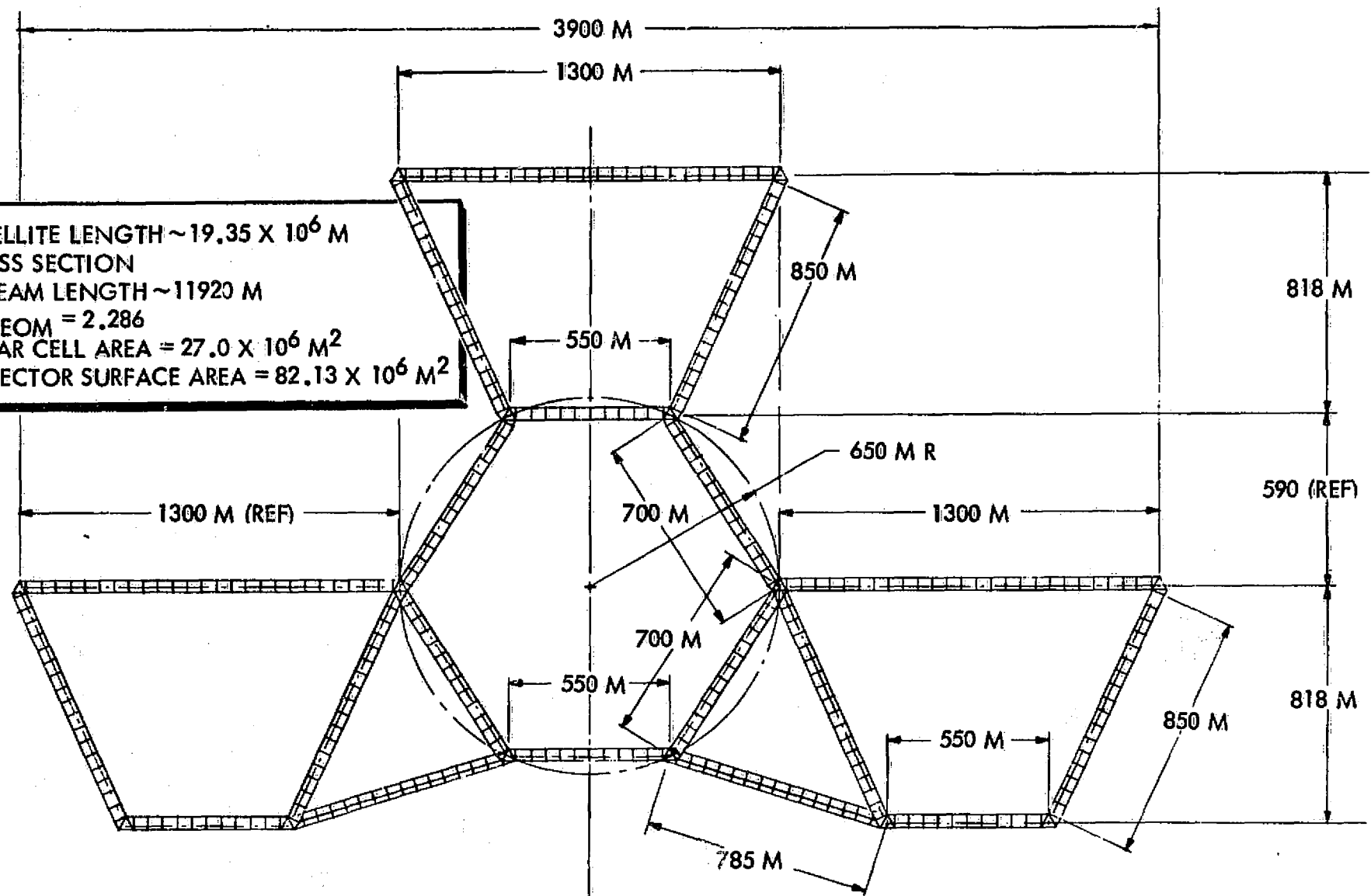


SPS STRUCTURAL CROSS-SECTION (65°, 3-TROUGH)

This chart shows the SPS structural cross-section used to model the 65° (3 troughs) reflector. The model uses a 650-meter radius rotary joint and structure as shown.

SPS STRUCTURAL CROSS-SECTION (65°, 3 TROUGH)

- SATELLITE LENGTH $\sim 19.35 \times 10^6$ M
- CROSS SECTION
BEAM LENGTH ~ 11920 M
- CRGEOM = 2.286
- SOLAR CELL AREA = 27.0×10^6 M²
- REFLECTOR SURFACE AREA = 82.13×10^6 M²

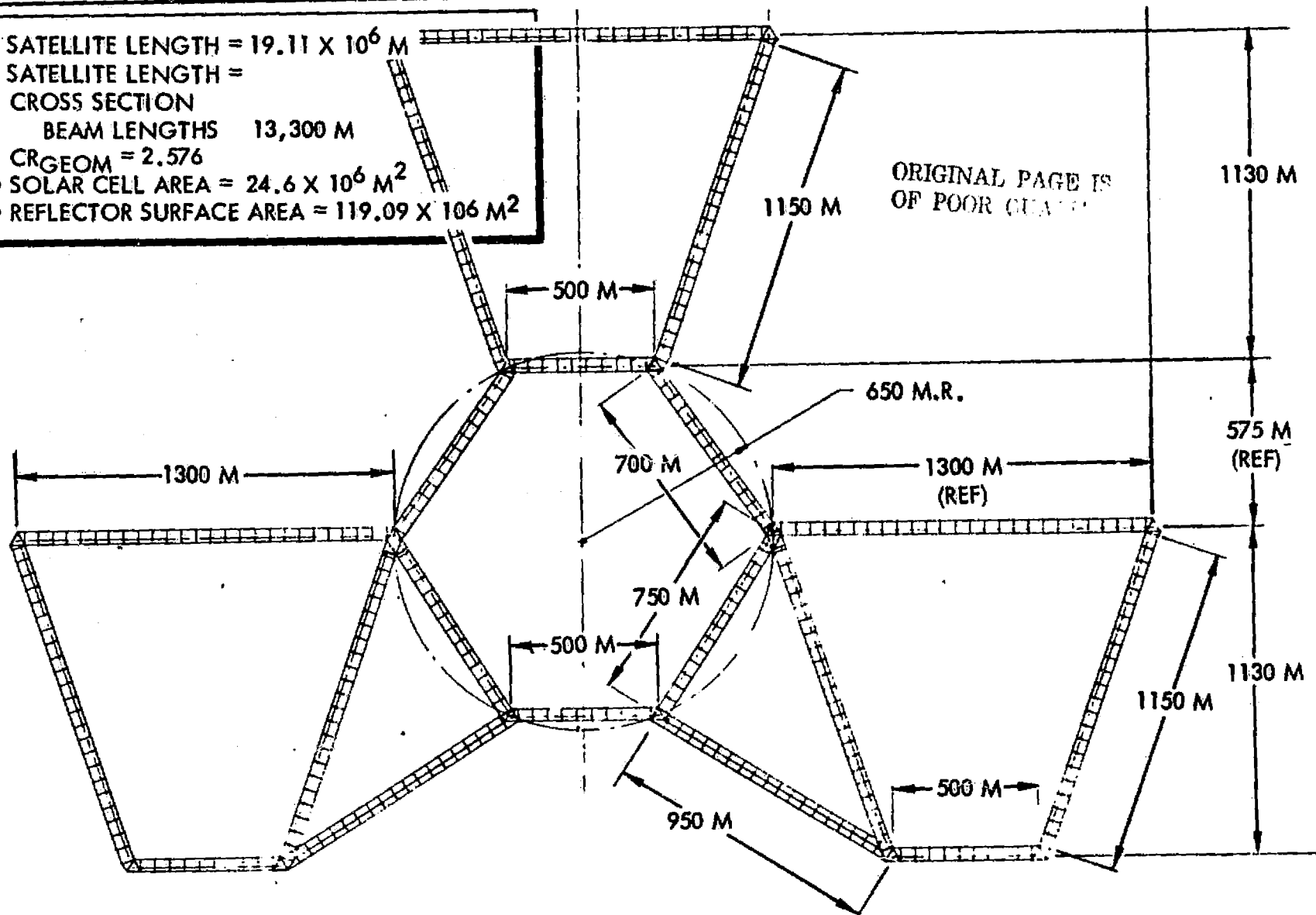


SPS STRUCTURAL CROSS-SECTION (71°, 3-TROUGH)

This chart shows the SPS structural cross-section used to model the 71° (three troughs) reflectors. The model uses 650-meter radius rotary joint and structures as shown.

SPS STRUCTURAL CROSS-SECTION (71°, 3 TROUGH)

- SATELLITE LENGTH = $19.11 \times 10^6 \text{ M}$
- SATELLITE LENGTH =
- CROSS SECTION
- BEAM LENGTHS 13,300 M
- CRGEOM = 2.576
- SOLAR CELL AREA = $24.6 \times 10^6 \text{ M}^2$
- REFLECTOR SURFACE AREA = $119.09 \times 10^6 \text{ M}^2$

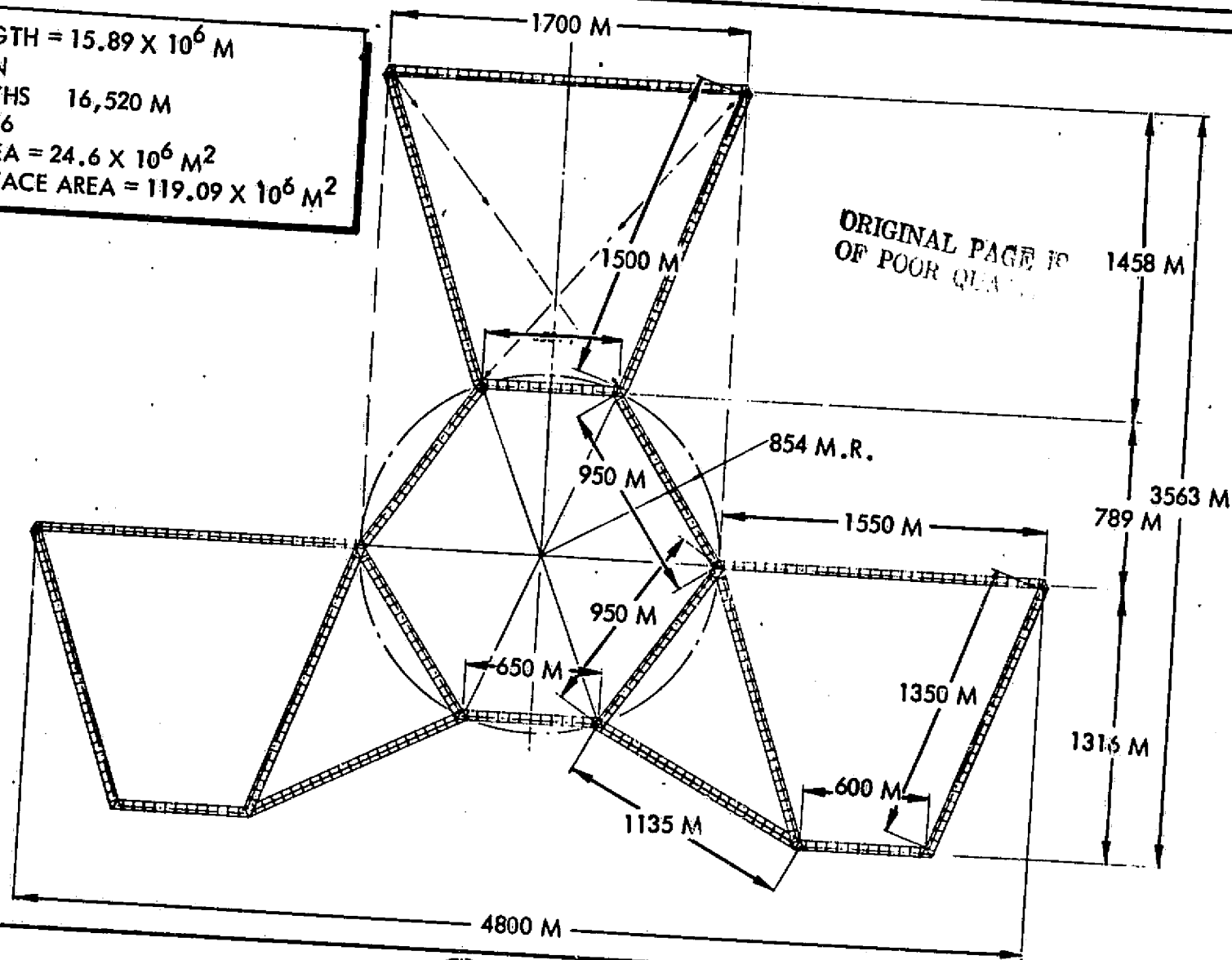


SPS STRUCTURAL CROSS-SECTION (71°, 3-TROUGH)
(SAME SOLAR CELL BLANKET WIDTHS)

This chart shows an alternate for the SPS structural cross section of 71-degree reflector angle (three troughs) reflectors. This model uses an 854-meter radius rotary joint as shown. This configuration has the solar blanket width of 650 meters and larger radius of rotary joint, compared to the previously variable blanket area with fixed radius (650 meters) rotary joint.

SPS STRUCTURAL CROSS SECTION (71°, 3 TROUGH)
(SAME SOLAR CELL BLANKET WIDTHS)

SATELLITE LENGTH = 15.89×10^6 M
CROSS SECTION
BEAM LENGTHS 16,520 M
CRGEOM = 2.576
SOLAR CELL AREA = 24.6×10^6 M²
REFLECTOR SURFACE AREA = 119.09×10^6 M²



COMPARISON OF REFLECTOR ANGLES

Performance and weight comparison was made for the solar cell array configurations previously shown with reflector angles of 60° , 65° , and 71° . Weight items affected included array structure, solar cells, reflectors, and conductors. The results of this comparison is shown in the chart. NOTE: The net weight variation is minor. Bracketed mass numbers are reference values.

COMPARISON OF REFLECTOR ANGLES

PERFORMANCE PAR. AND MASS ELEMENT	REFLECTOR ANGLE		
	60°	65°	71°
TEMPERATURE °C	113	119	125
η (T)	.1816	.179	.176
SOLAR INPUT (W/M ²)*	1319.5		→
CRGEOM.	2.0	2.286	2.576
CR _{EFF} (EOL)	1.83	2.067	2.308
ENERGY ONTO CELL (W/M ²)	2414.7	2727.4	3045.4
ENERGY CONVERTED (W/M ²)	438.5	488.2	536.0
ARRAY DESIGN FACTOR (.89)	390.27	434.5	477.0
SEASONAL VARIATION (.91)	355.1	395.4	434.1
ENVIR. DEGRAD (.96)	340.9	379.6	416.7
SOLAR CELL AREA (10 ⁶ M ²)	30.06	27.0	24.6
REFL. RATIO TO CELLS	2.0	3.04	4.84
REFL. SURFACE (10 ⁶ M ²)	60.12	82.13	119.09
DELTA MASS (10 ⁶ KG)			
STRUCT. & MECH.	(3.777)	+0.001	+0.222
SOLAR BLANKET	(7.586)	-0.771	-1.376
REFLECTOR	(1.088)	+0.398	+1.067
POWER DISTR.	(1.166)	+0.054	+0.062
SUBTOTAL Δ'S	(13.617)	-0.318	-0.025

NOTE: *SUMMER SOLSTICE



SUBSYSTEM COST COMPARISON AS A FUNCTION OF REFLECTOR ANGLE

This chart shows the SPS subsystem cost comparison as a function of reflector angle. As the reflector angles increase, even with the savings of the cost/mass, it is insufficient to overcome the penalty from the added structure complexity. Bracketed values are shown for reference costs. The recommendation resulting from this comparison is that the present baseline, utilizing CR = 2 and 60° slant angle, should be retained.

SUBSYSTEM COST COMPARISON AS A FUNCTION OF REFLECTOR ANGLE

COST IN MILLIONS OF DOLLARS (TFU)

SUBSYSTEM ELEMENTS	REFLECTOR ANGLE			COST FACTOR
	60°	65°	71°	
STRUCTURES	(390.554)	+ .081	+ 17.9	\$80.66/KG
SOLAR BLANKET	(1978.481)	-197.823	-352.989	\$64.65/M ²
REFLECTORS	(150.79)	+ 52.24	+138.4	\$ 2.52/M ²
WIRING	(3.64)	+ .08	+ .09	\$ 1.52/KG
TRANSPORTATION	(678.525)	- 15.525	- 1.2	\$37.5/KG
SUBTOTAL COST	(3201.99)	-160.947	-197.80	

NOTE: AVG COST REDUCTION FACTOR ~ .8611 TFU

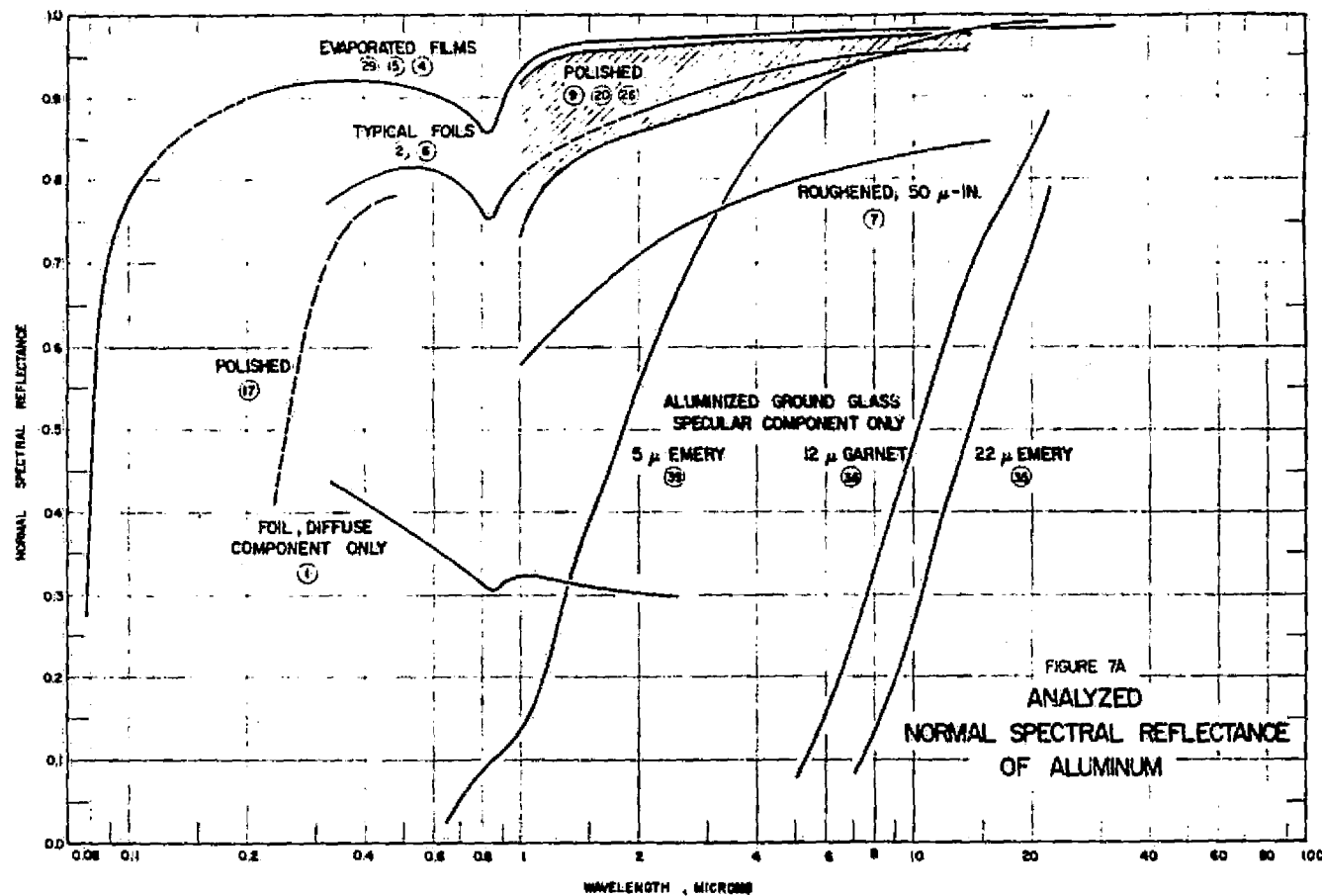
✓ STAY WITH 60° REFL. ANGLE
 • COST/MASS SAVINGS INSUFFICIENT
 TO OVERCOME ADDED COMPLEXITY



ALUMINUM SPECTRAL REFLECTANCE DATA

This chart exhibits the optical reflectance of aluminum as presented by Touloukian et al in the Thermophysical Properties of Matter series. It shows the reduction in reflectance of evaporated films in the peak conversion wavelength region of GaAlAs, which results in decreased reflection of desired solar radiation from the concentrators.

ALUMINUM SPECTRAL REFLECTANCE DATA



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REFERENCE: THERMO PHYSICAL PROPERTIES
HANDBOOK



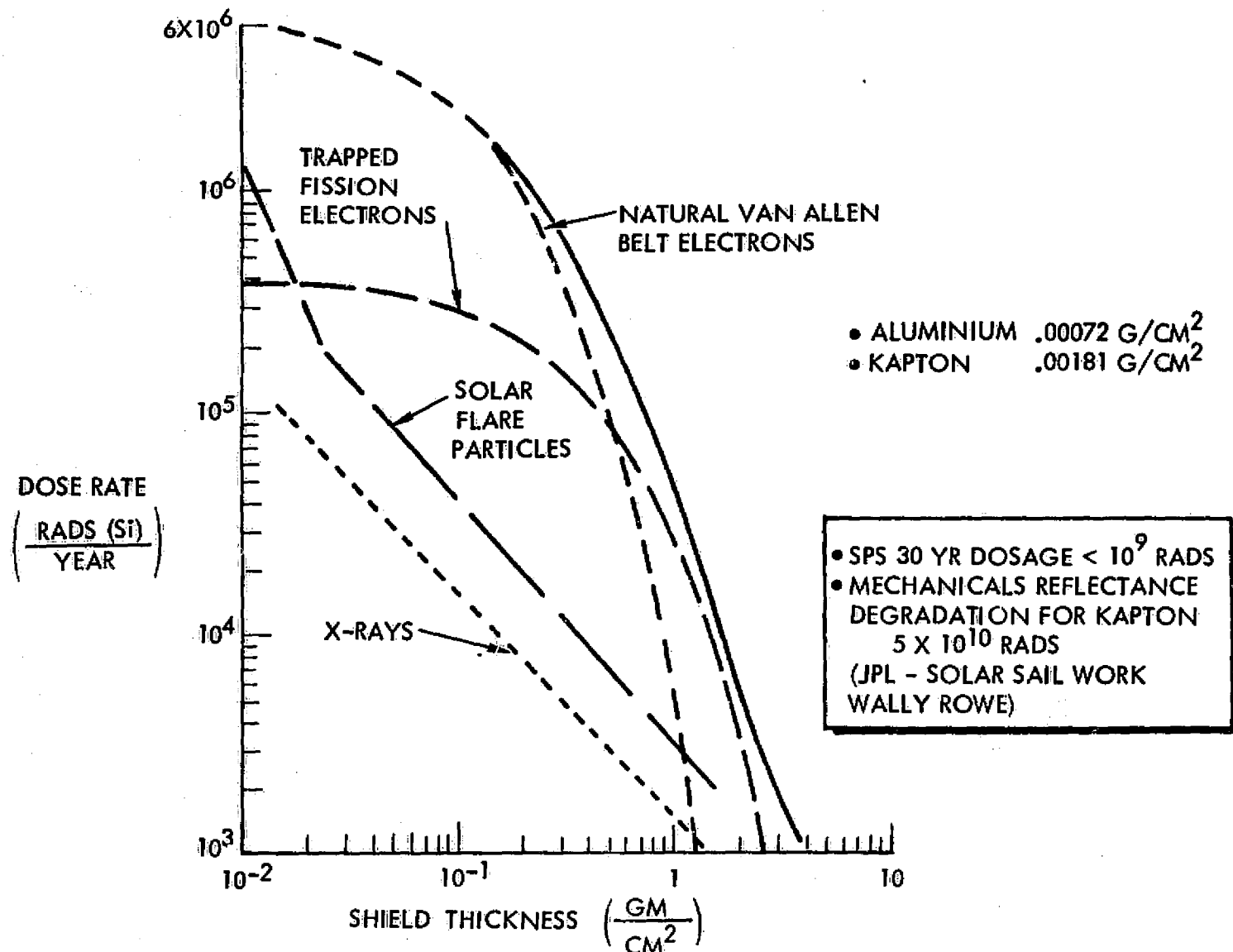
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RADIATION DOSE RATES IN 24-HR ORBIT

Radiation dose rates at geosynchronous orbit, 0° inclination as functions of shield thickness are presented in this chart. In this 24-hour orbit, the natural Van Allen Belt electrons are the primary radiation dose factor. Solar flare particle and trapped fission electrons have secondary effect, except for shield thickness $\geq 1 \text{ gm/cm}^2$. The 30-year dosage is $< 10^9$ rad.

Test results reported by JPL (Wally Rowe) indicate the threshold for mechanical reflectance degradation from kapton is 5×10^{10} rad.

RADIATION DOSE RATES IN 24 HR - GEOSYN ORBIT



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SPECULAR REFLECTANCE (0.4 μm - 0.9 μm)

A more appropriate concentrator reflectivity can be derived from measured data in the conversion band of GaAlAs. Data measured at Sandia for aluminized Teflon indicate a beginning-of-life magnitude of 0.87, and this value will be applied to the SPS reflectors. Lifetime deterioration estimates also have been recomputed. A math model of the meteoroid exposure levels has been developed. The model indicates that a loss of about one-half of one percent can be expected. Because of the relatively low temperatures of the reflectors, thermal cycling degradation due to eclipse passage should be slight and is estimated to be one percent. The reflector radiator resistance has been increased from earlier estimates because it has been shown that the test data used as a basis for predicting radiation losses greatly exceeded the operation spacecraft environmental exposure. Consideration of these factors indicates that an end-of-life value of 0.827 can be expected.

SPECULAR REFLECTANCE (0.4 μ m - 0.9 μ m)

SILVERED GLASS $\sim$ 0.83

3M SCOTCHCAL 500 $\sim$ 0.85 (ALUMINIZED ACRYLIC)

SHELD AHL ALUMINIZED TEFLON $\sim$ 0.87⁽¹⁾ (B.O.L.)

THIRTY YEAR DEGRADATION FACTORS

METEOROID FACTOR = 0.995

THERMAL CYCLING = 0.990

(DUE TO EXPANSION/CONTRACTION
INITIATED BY ECLIPSE PASSAGE)
(ALLOWANCE)

RADIATION RESISTANCE = 0.965

30 YEAR E.O.L. REFLECTIVITY = 0.827

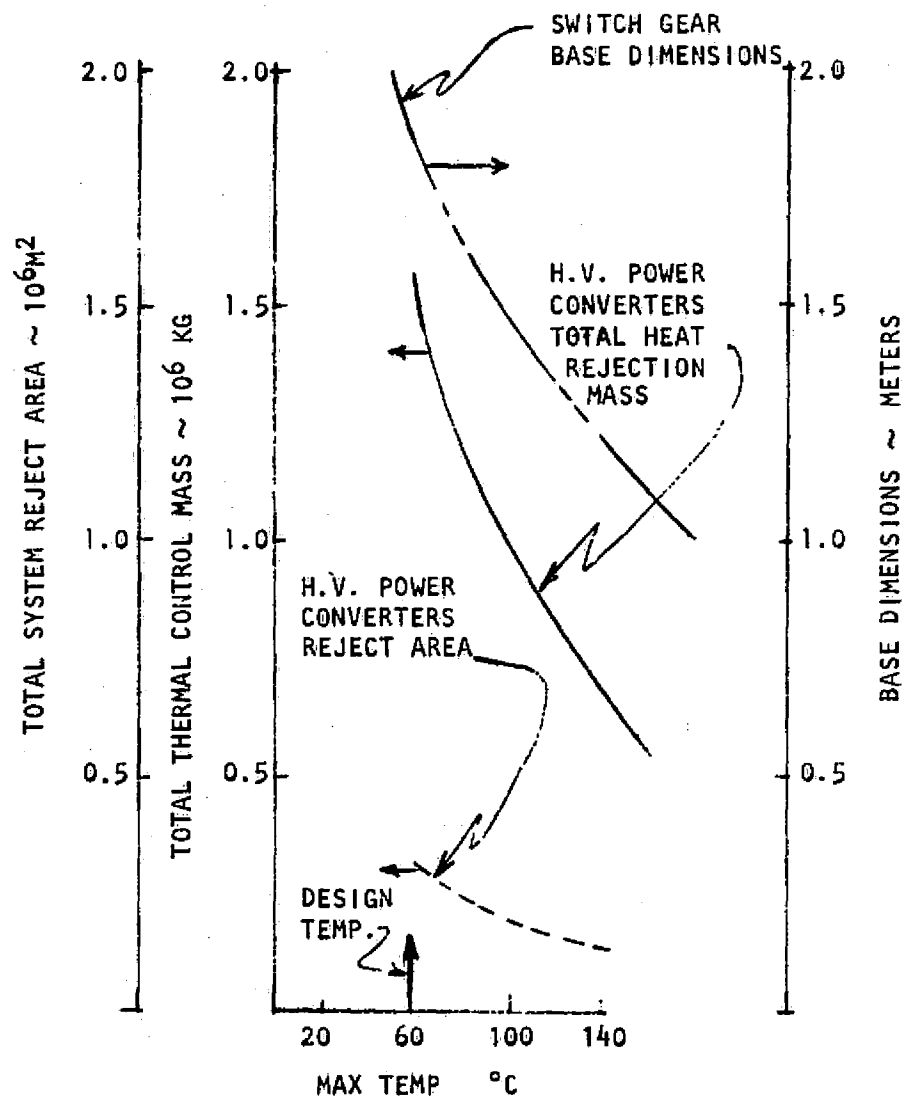
(1) REFERENCE: R. B. PETTIT
NASA A77-49074



POWER DISTRIBUTION COMPONENT THERMAL CONTROL

This chart depicts the results of an analysis to define thermal control requirements for the switch gear and high voltage dc-dc converters. For the switch gear the waste heat can be rejected passively by increasing case size to the required dimension. The data shown on the figure is applicable to a cubic configuration. To cool the converters an active control loop is required. Due to their power level, thermal efficiency, and operating temperature restriction, relatively large radiator systems are required. Some possible technology advances which might reduce the impact of these systems are also presented.

POWER DISTRIBUTION COMPONENT THERMAL CONTROL



SWITCH GEAR

POWER LEVEL = 12 MEGAWATTS
 η = 0.999
 THERMAL LOSS = 12000 WATTS

H.V. DC-DC CONVERTERS

POWER LEVEL = 300 MEGAWATTS
 η = 0.96
 NO. UNITS = 32
 THERMAL LOSS = 12 MEGAWATTS (EACH)

SYSTEM WEIGHT MINIMIZATION

- DISK CONFIGURATION AND/OR HEMISPHERICAL
- HEAT PIPE INTEGRATED INTO RADIATOR
- OPTIMIZED FIN GEOMETRY
- HIGHER TEMPERATURE ELECTRONICS
- WASTE HEAT USAGE

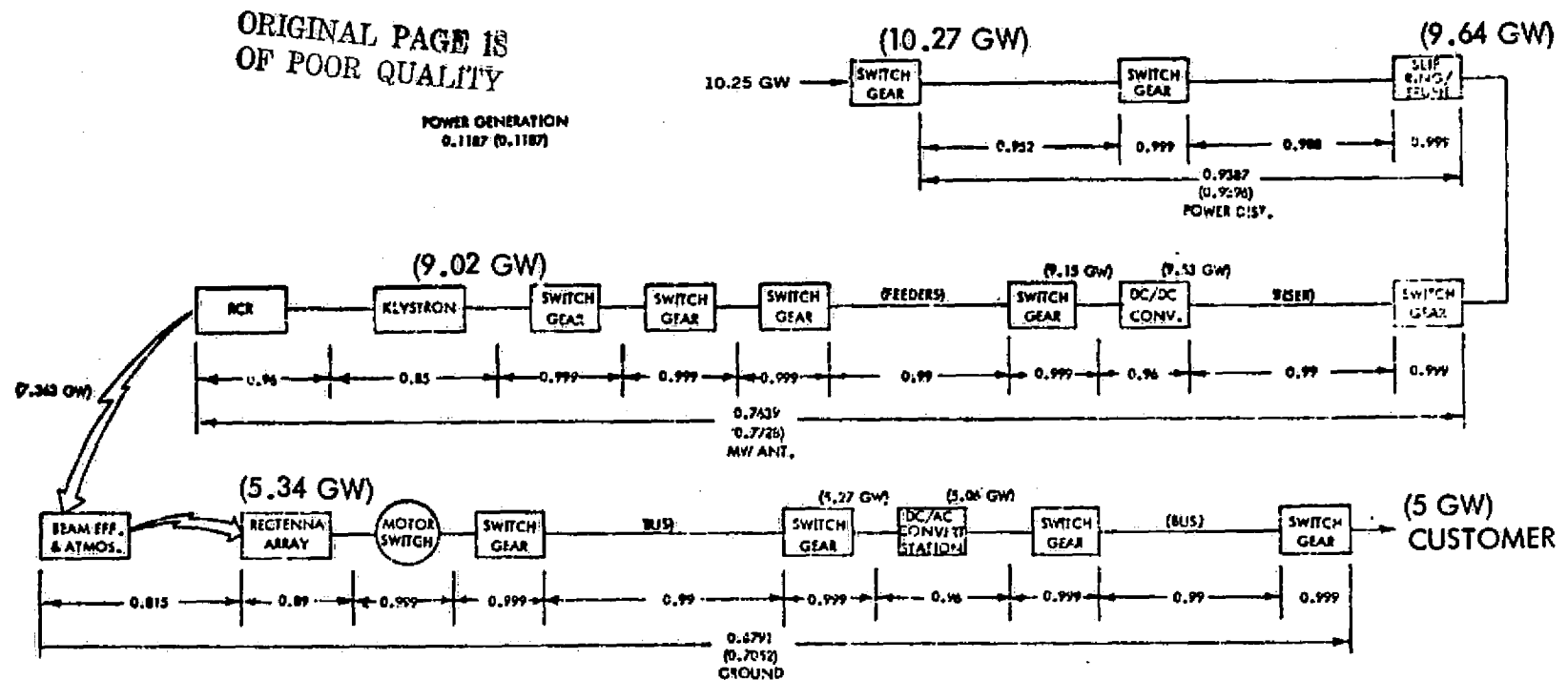
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SYSTEM EFFICIENCY CHAIN—PHOTOVOLTAIC (CR = 2)

This chart shows the device/element power efficiency estimates established to date. Prior estimates of element efficiency is included in brackets. The overall efficiency of operations is presently estimated to be approximately 5.78%. This represents a decrease of 0.3% from the estimate presented at the conclusion of the previous SPS study. The major changes involved additional switch gear and a reduction in dc conversion efficiency at the rectenna site.

SYSTEM EFFICIENCY CHAIN - PHOTOVOLTAIC (CR-2)



ζ OVERALL = POWER GEN. × POWER DIST. × MW ANT. × GROUND
 (11.87%) (93.87%) (76.39%) (67.91%)
 = 5.78% (WAS 6.08%)



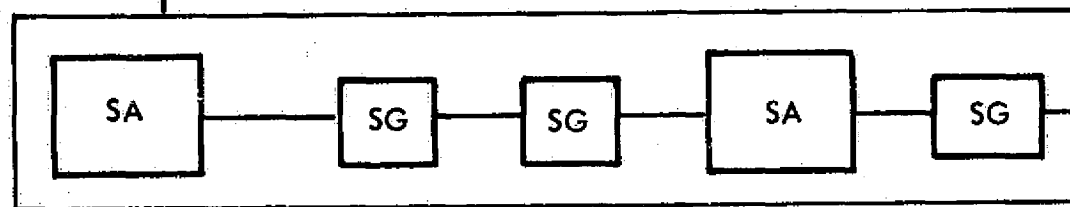
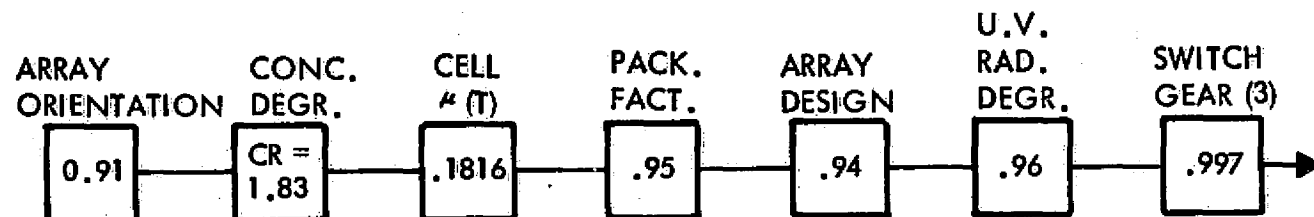
SOLAR ARRAY EFFICIENCY CHAIN

A continuous review of subsystem efficiencies has been maintained in order to provide updated efficiency factors for the design of the SPS. The efficiencies of the major components for the solar array are presented. The major considerations of this efficiency chain are the GaAlAs solar cell at 18.16% for the solar cell operating temperature.

The summer solstice is taken as the sizing requirement since power output is a minimum during this period. Operating temperatures calculated are the following: $T_{\text{EQUINOX}} = 125 \text{ C}$; $T_{\text{summer solstice}} = 113 \text{ C}$; and $T_{\text{winter solstice}} = 119 \text{ C}$.

Specific solar array power output is $336.6 \text{ watts/meter}^2$ as shown and utilized in solar array sizing.

SOLAR ARRAY EFFICIENCY CHAIN



SUMMER SOLSTICE	
SOLAR INPUT	1319.5 W/M ²
ENERGY ONTO	
CELLS (CR = 1.83)	2414.7
M (T) (.1816)	438.5
DESIGN (.89)	390.27
SEASONAL (.91)	355.14
POWER DEGRAD (.96)	340.94
MARGIN (.987)	336.6 W/M ²
B.O.L. MAX SEASONAL ADJUSTMENT 1.217 = > 409.7 W/M ²	

138.85 MW
(151.47 MW)

138.85 MW
(151.47 MW)

276.87 MW X 24 = 6.645 GW
(302.03 MW) X 12 = 3.626 GW
10.27 GW

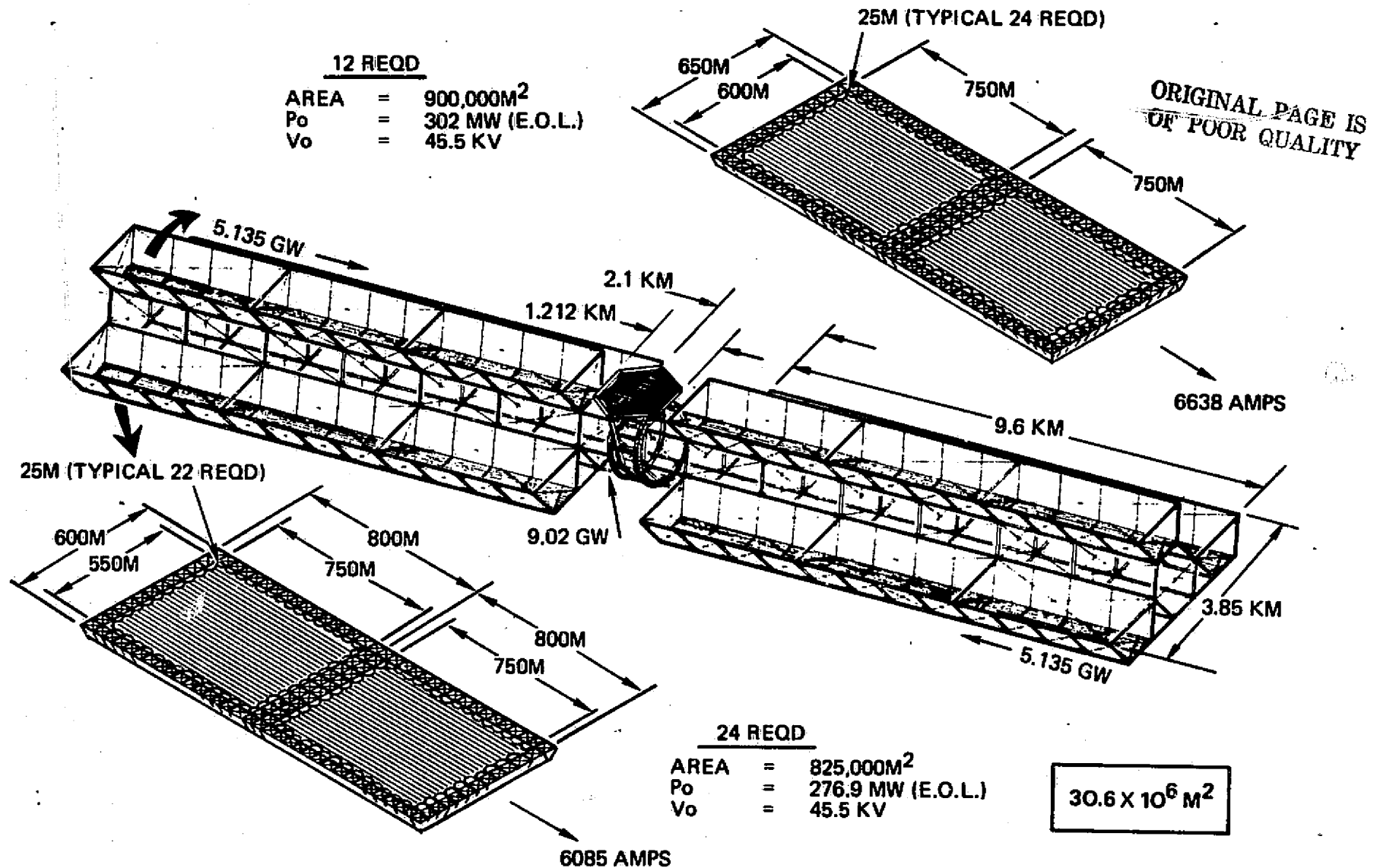


SOLAR BLANKET CONCEPT

The solar blanket layout for the point design configuration is shown in the Figure. The solar panel in the top trough (effective cell area) measures $600\text{m} \times 750\text{m} \times 2$ for $900,000 \text{ m}^2$. Twelve panels are required for the top trough. The panels for the two lower troughs are slightly smaller in width and measure $550\text{m} \times 750\text{m} \times 2$ for $825,000 \text{ m}^2$ (effective cell area). Twenty-four panels are required for the bottom troughs. The total deployed solar area for the SPS is $30.6 \times 10^6 \text{ m}^2$ which is comprised of $10.8 \times 10^6 \text{ m}^2$ in the top trough and $19.8 \times 10^6 \text{ m}^2$ in the bottom troughs.

Two bays are used in the makeup of the 45.5 kV. Switch gears are provided at each end of a string of solar cells for isolation and maintenance. Voltage regulation as well as beginning of life and seasonal excess power will be controlled by selective switching of isolation switch gear on array modules.

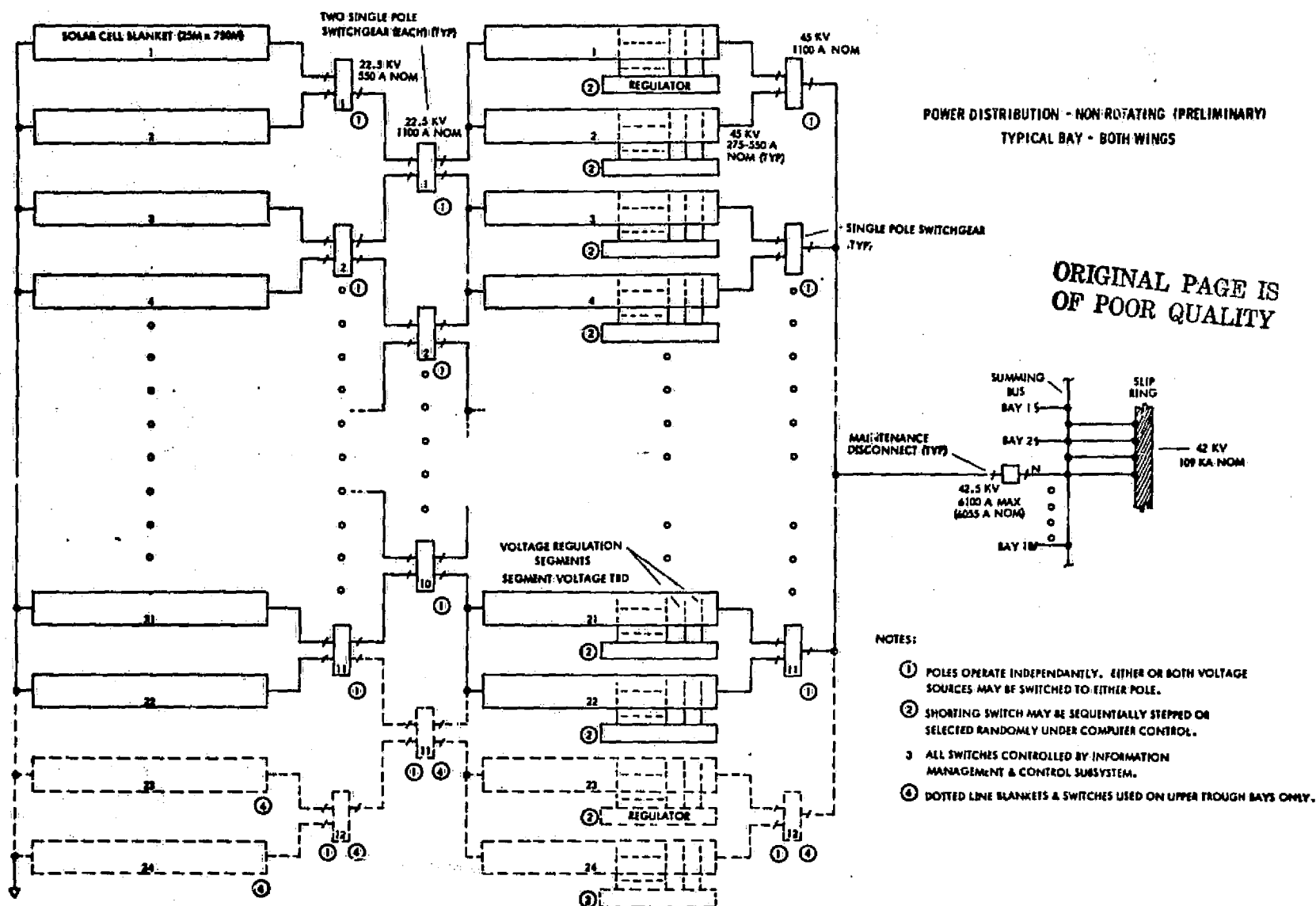
SOLAR BLANKET CONCEPT



SOLAR CELL CONFIGURATION—TYPICAL SEGMENT (1 OF 36)

This chart illustrates the electrical flow diagram of a typical solar cell bay located on either wing element. Included on the diagram are the switching devices needed to operate the satellite power system. The power network is entirely under the control of the on-board data processing system, with the possible exception of the final protective switchgear at the summing bus which also may incorporate a current overload detector. The system power and voltage are regulated by the data system through appropriate segment selection and shorting. The element labeled as a regulator is a shorting switch to modify the effective string output voltage. The outputs of the bays (18) are summed and routed to the appropriate slip ring by secondary feeders.

SOLAR CELL CONFIGURATION - TYPICAL SEGMENT (1 OF 36)

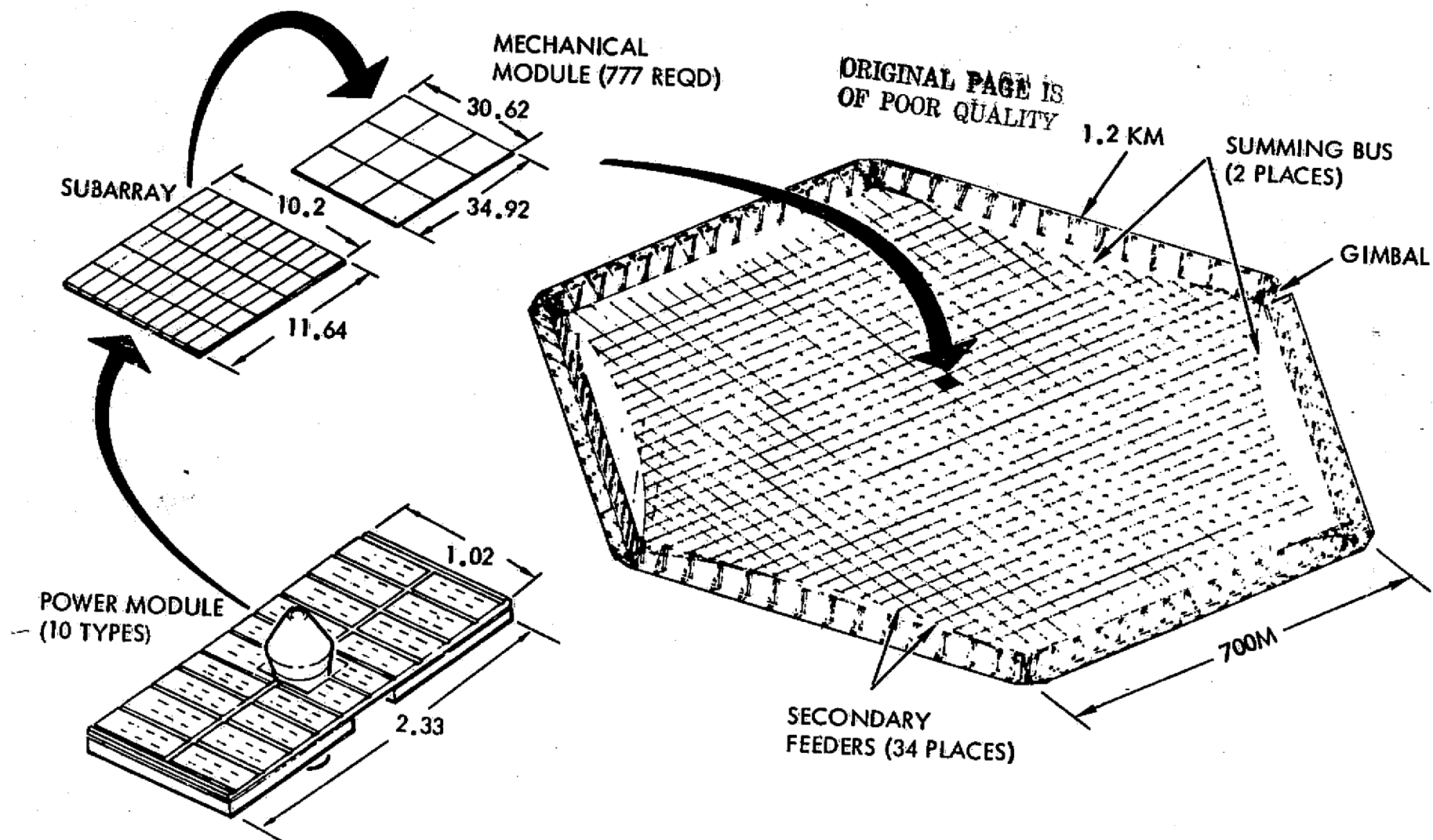


MICROWAVE TRANSMISSION SYSTEM—SATELLITE ANTENNA

This chart depicts the basic configuration, including overall dimensions of the selected antenna structure concept.

The smallest antenna building block is the power module, which varies in size from the one illustrated (which is used at the center portion of the antenna) to 3.40 by 5.82 meters at the periphery of the antenna. Ten different power module sizes are used to comprise the antenna element. Each power module has a klystron located in its center. The power modules are arranged into subarrays measuring 10.2 by 11.64 meters. Each subarray has its own phase control electronics. Nine subarrays are connected to form a mechanical module 30.82 by 34.92 meters.

MICROWAVE TRANSMISSION SYSTEM - SATELLITE ANTENNA



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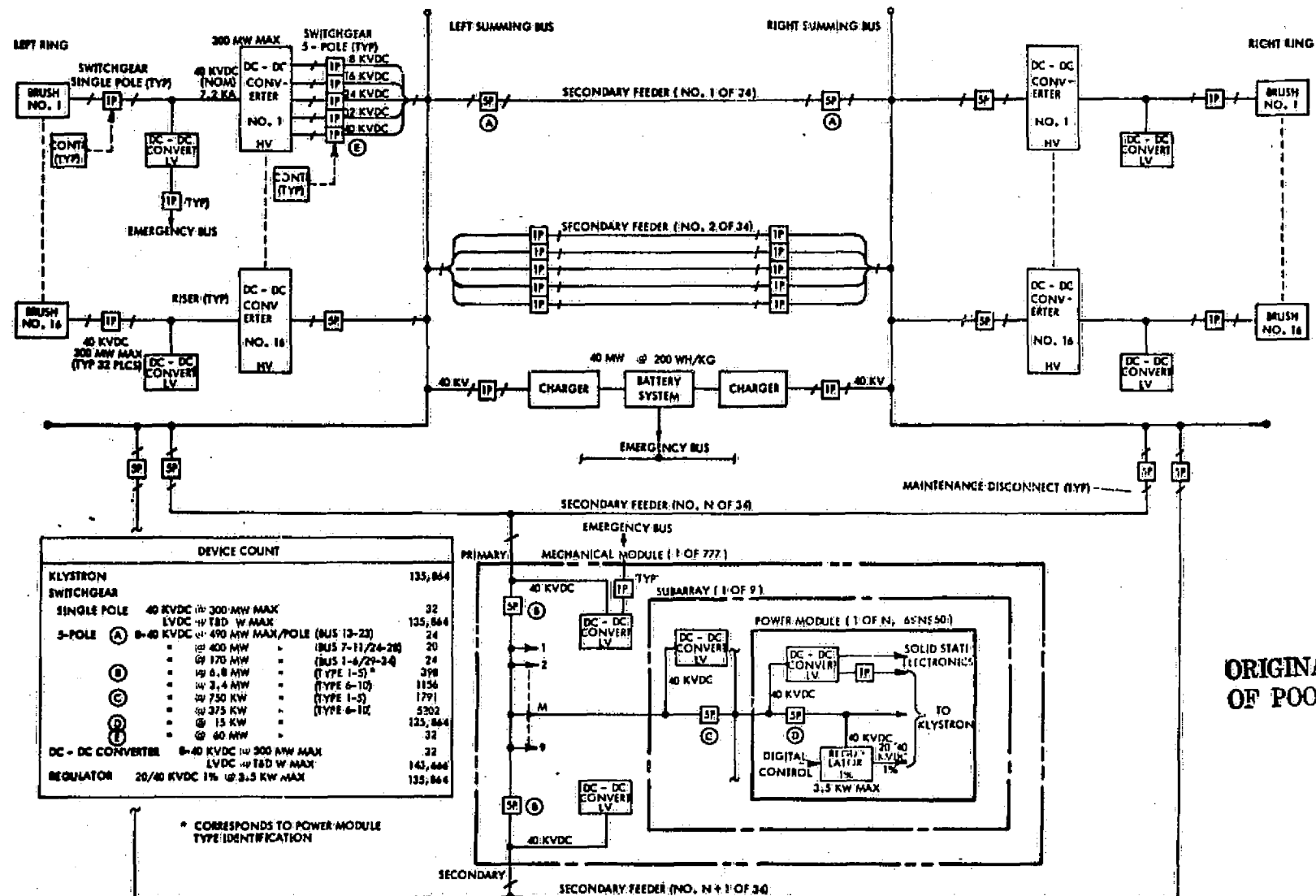
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MICROWAVE ANTENNA—POWER DISTRIBUTION

The rotating elements of the power distribution system consist of the slip ring brushes, the power risers and dc-dc converters, the secondary feeders, and the dc-RF converters (klystrons). The distribution concept selected permits full operational capability with almost any single failure. For example, riser or dc-dc converter failures are overcome by oversizing of buses and converters, permitting increased current loads on remaining functional paths; secondary bus failures are overcome by providing secondary power paths for every mechanical module; etc.

The chart identifies the power/current levels (maximum) required at every switching point. Also shown is the emergency bus and energy storage subsystem required to maintain powered status for supporting subsystems and klystron filaments during periods of solar eclipse.

MICROWAVE ANTENNA - POWER DISTRIBUTION

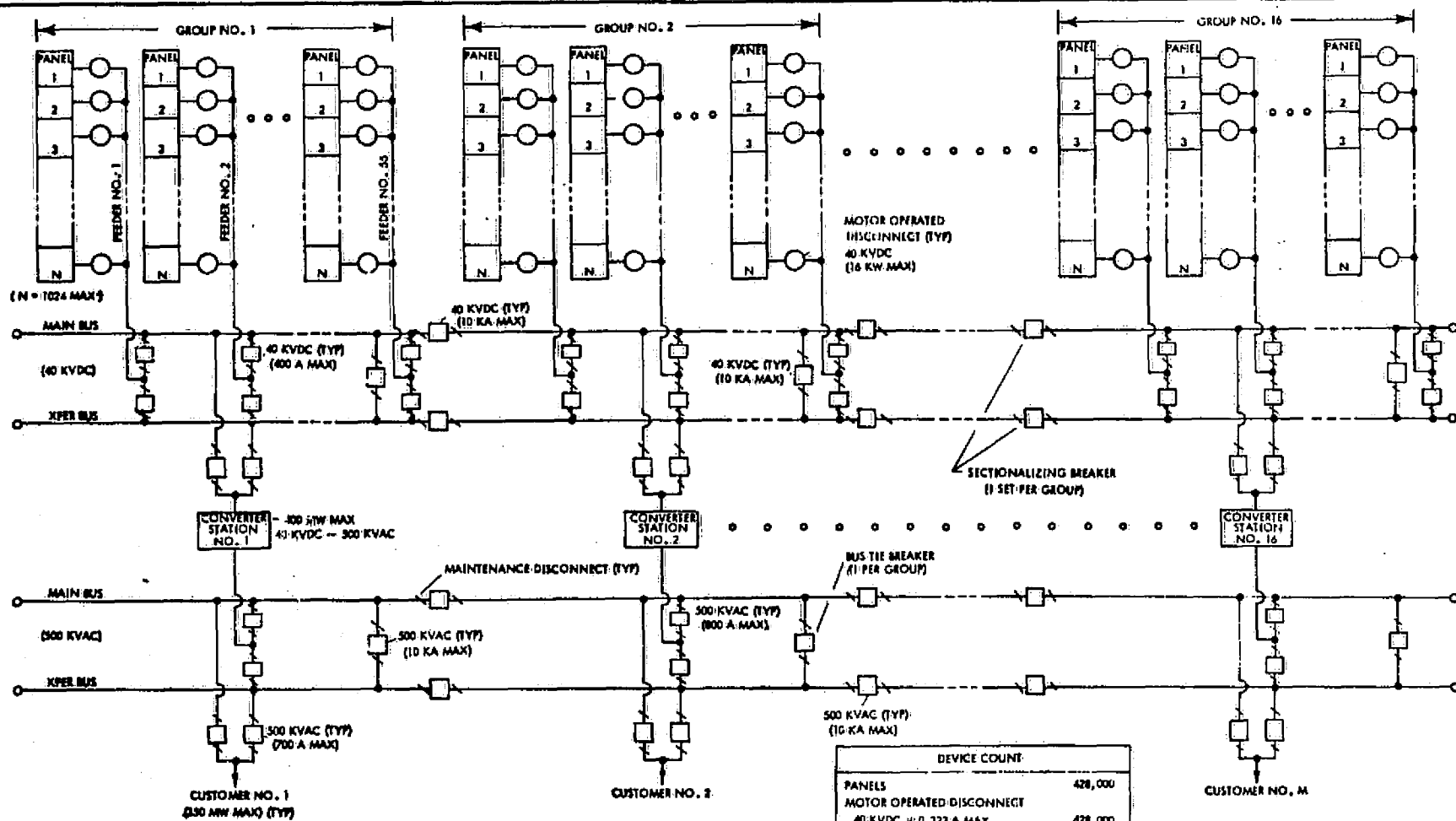


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DEVICE COUNT	
PANELS	428,000
MOTOR OPERATED DISCONNECT	
40 KVDC @ 0.333 A MAX	428,000
SWITCHGEAR	
40 KVDC @ 400 A MAX	1760
40 KVDC @ 10 KA MAX	16
500 KVAC @ 700 A MAX	32
500 KVAC @ 800 A MAX	16
500 KVAC @ 10 KA MAX	TBD
CONVERTERS	
40 KVDC - 500 KVAC @ 800 A MAX	16
40 KVDC - LOW VOLTAGE	TBD



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MASS PROPERTIES STATUS

The mass of the current SPS versus Exhibit A/B are shown in the chart, and has resulted in an 8.3% increase in dry weight. The following tabulation identifies the reasons for these mass changes:

Collector Area

Primary structure—Eighteen additional 50-m tribeams across top of reflector bays.

Attitude control—Updated to reflect final Exhibit A/B.

Power conditioning equipment—Addition of 40,000 low-voltage converters plus increase in switch gears due to drop in system efficiencies.

Power distribution—Increase in conductors and slip rings due to drop in system efficiencies.

Antenna Section

Primary structure—Duplication in slip ring support.

Thermal control—Radiator system added (320,000 m²) for high-voltage converters.

Power conditioning equipment—Addition of 144,000 low-voltage converters and 136,000 regulators plus increase in switch gear due to lower system efficiencies.

Power distribution—Decrease in conductors and brushes due to drop in system efficiencies.

SOLAR PHOTOVOLTAIC POWER CONVERSION - MASS STATEMENT

SUBSYSTEM	MASS, KG X 10 ⁶		
	EXHIBIT A/B	MASS	CURRENT
COLLECTOR ARRAY			
STRUCTURE AND MECHANISMS	(3.777)	(+ 0.048)	(3.825)
PRIMARY STRUCTURE	2.856	+ 0.048	2.904
SECONDARY STRUCTURE	0.688	—	0.688
MECHANISM	0.233	—	0.233
ATTITUDE CONTROL	(0.095)	(+ 0.021)	(0.116)
POWER SOURCE	(8.831)	—	(8.831)
SOLAR PANELS	7.722		7.722
SOLAR REFLECTORS	1.108		1.108
POWER DISTRIBUTION AND CONTROL	(1.166)	(+ 0.181)	(1.347)
POWER CONDITIONING EQUIPMENT	(0.259)	(+ 0.133)	(0.392)
POWER DISTRIBUTION	(0.907)	(+ 0.048)	(0.955)
CONDUCTORS AND INSULATION	0.699	+ 0.037	0.736
SLIP RINGS	0.208	+ 0.011	0.219
INFORMATION MANAGEMENT & CONTROL	(0.050)		(0.050)
DATA PROCESSING	0.021		0.021
INSTRUMENTATION	0.029		0.029
TOTAL ARRAY, DRY	13.919	+ 0.250	14.169



SOLAR PHOTOVOLTAIC POWER CONVERSION - MASS STATEMENT (CONTINUED)

SUBSYSTEM	MASS, KG X 10 ⁶		
	EXHIBIT A/B	MASS	CURRENT
ANTENNA SECTION			
STRUCTURE & MECHANISM	(1.685)		(1.685)
PRIMARY STRUCTURE	0.408	-0.003	0.405
SECONDARY STRUCTURE	0.890		0.890
ANTENNA	0.190		0.190
MECHANISM	0.197		0.197
THERMAL CONTROL	(1.408)	(+1.049)	(2.457)
KLYSTRON COOLING	0.851		0.851
INSULATION	0.557		0.557
RADIATOR	0	+1.049	1.049
MICROWAVE POWER	(7.012)		(7.012)
KLYSTRONS	4.250		4.250
ATT. SEN. ELECTRONICS & PHASE CONTROL	0.142		0.142
WAVEGUIDES	2.620		2.620
POWER DISTRIBUTION & CONTROL	(3.469)	(+1.047)	(4.516)
POWER CONDITIONING EQUIPMENT	(1.635)	(0.831)	(2.466)
POWER DISTRIBUTION	(1.834)	(+0.216)	(2.050)
CONDUCTOR & INSULATION	1.695	+0.209	1.904
SLIP RING BRUSHES	0.139	+0.007	0.146
INFORMATION MANAGEMENT & CONTROL	(0.630)		(0.630)
DATA PROCESSING	0.380		0.380
INSTRUMENTATION	0.250		0.250
TOTAL ANTENNA SECTION	14.204	+2.093	16.297
TOTAL SPS DRY	28.123	+2.343	30.466
GROWTH 30%	8.437	+0.703	9.140
TOTAL SPS DRY WITH GROWTH	36.560	+3.046	39.606



SPS STRUCTURAL ANALYSIS—STATUS

This chart summarizes the status of the NASTRAN computer program analysis of the SPS structure. The first case (Case 1) has been run using aluminum as the tribeam girder material, with a mechanical loading due to a pretensioning loading of 75 psi in the reflectors, but with no pretensioning in the X-bracings, and with a thermal profile shown in the following chart. The program output data for member stresses are being evaluated.

SPS STRUCTURAL ANALYSIS

STATUS:

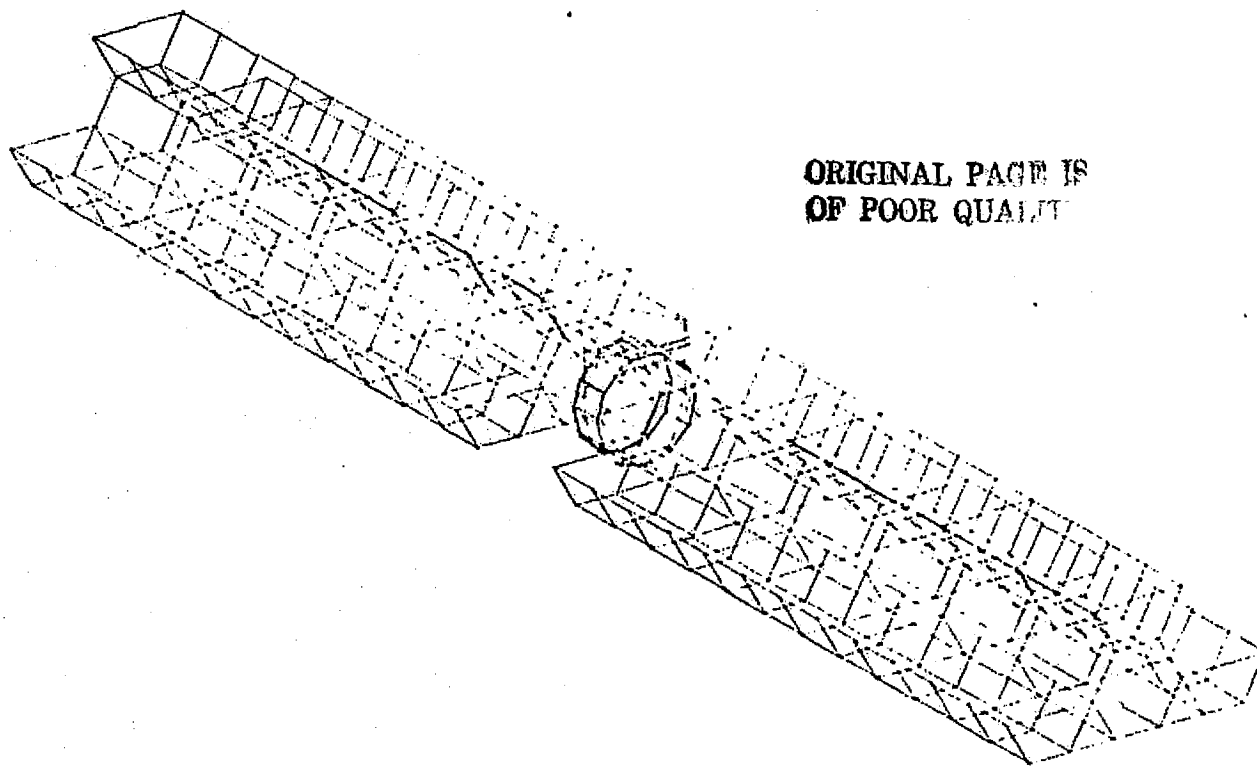
- SUBSTRUCTURE MODELING COMPLETE
- SUBSTRUCTURES PROPERLY CONNECTED TO FORM COMPLETE SPS CONFIGURATION
- TRIBEAM GIRDER PHYSICAL PROPERTIES UPDATED AND FED INTO COMPUTER MODEL
- INITIAL CASE RUN ON NASTRAN
 - MATERIALS
 - TRIBEAM GIRDERS: ALUMINUM ($E = 6.895 \times 10^{10}$ Pa)
 - X-TENSION BRACES: STEEL ($E = 20.7 \times 10^{10}$ Pa)
 - INCLUDED OPERATIONAL TEMPERATURE DISTRIBUTION (ASSEMBLY TEMPERATURE ASSUMED = 0° C)
 - INCLUDED MECHANICAL LOADS (REFLECTOR PRETENSION (75 PSI) REACTION FORCES)
 - NO PRETENSIONING OF X-TENSION BRACES



NASTRAN STRUCTURAL MODEL—CRT OUTPUT

This chart depicts the CRT output of the combined SPS substructures used in the NASTRAN program for the structural analysis. Not shown in the CRT picture are the steel wire X-bracings. The combined structure is a makeup of the substructures shown in previous briefings.

SPS STRUCTURAL ANALYSIS



SPS STRUCTURE
CASE NO. 1, NO PRELOAD OF X-BRACING, ASSY TEMP. = 0.0 C

UNDEFORMED SHAPE



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PHOTOVOLTAIC STRUCTURAL CONFIGURATION TEMPERATURES

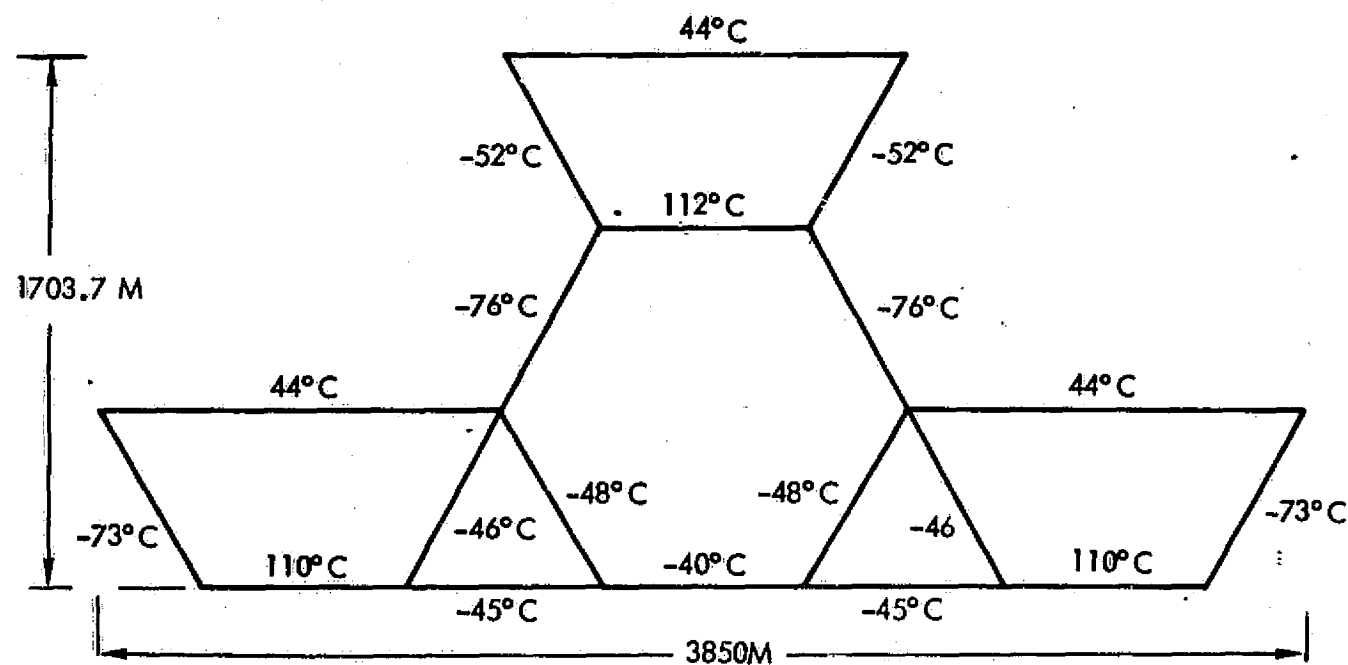
Temperature values for the "baseline" CR = 2 configuration used in the NASTRAN structural analysis are shown. The temperatures are for the non-rotating areas only; the temperatures for the antenna and rotating assembly are not shown, but the values used vary between 65°C and 130°C.

PHOTOVOLTAIC STRUCTURAL CONFIGURATION TEMPERATURES

COATED ALUMINUM
OPTICAL PROPERTIES

$\alpha = 0.4$

$\epsilon = 0.8$



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SPS STRUCTURAL ANALYSIS—INITIAL RESULTS

The initial observations of the results of Case 1 are summarized on this chart. Additional tribeam braces are required to reduce the maximum tribeam length for buckling to 1600 meters, assuming an end fixity of 2. The deflections of the structure are small, compared to the size of the system. Cross-sectional distortion of the unit are yet to be summarized from the program output data.

SPS STRUCTURAL ANALYSIS

- INITIAL OBSERVATIONS

- RESULTING STRESS LEVELS WITHIN MATERIAL BUCKLING CAPABILITY IF:

- MAXIMUM TRIBEAM GIRDER LENGTH BETWEEN JOINTS REDUCED TO 1600 METERS.
- JOINT FIXITY CONDITION APPROACHES 2
(1 = PINNED JOINT, 4 = FIXED JOINT)

- DEFLECTIONS

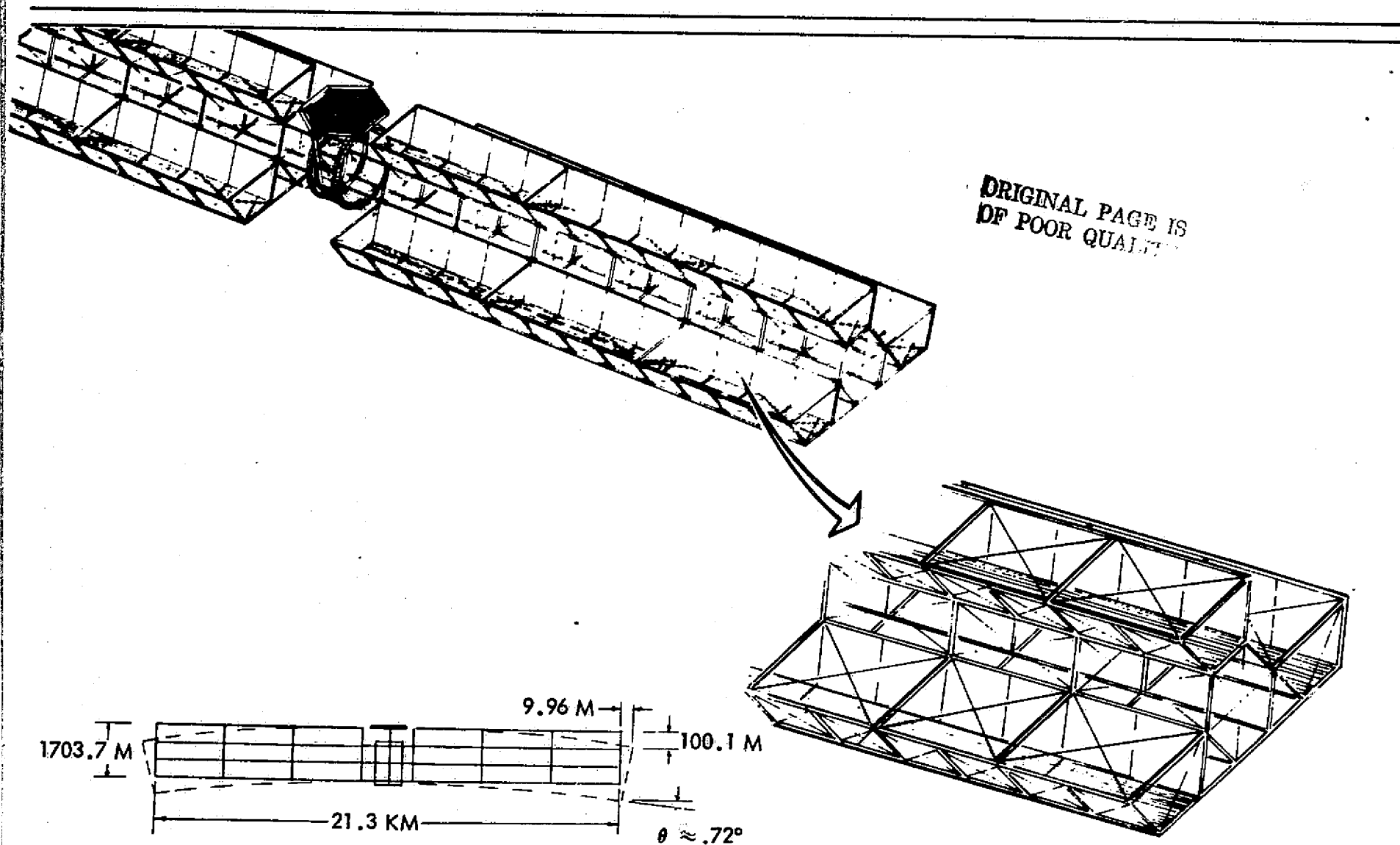
- SATELLITE GROWS APPROXIMATELY 20 METERS IN LENGTH
- OUT-OF-PLANE DEFLECTION AT TIPS IS APPROXIMATELY 100 METERS ($\theta \approx .72^\circ$)



SPS STRUCTURAL ANALYSIS—DESIGN CHANGE

This chart shows the design alteration to reduce the tribeam column length to 1600 meters to meet buckling criteria, and summary of the SPS structure tip deflections for Case 1. The deflections are small for the size of structure. The addition of the lateral tribeam braces increases the primary structural mass by approximately 106,000 kg.

SPS STRUCTURAL ANALYSIS



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SPS STRUCTURAL ANALYSIS—PLANNED EFFORT

This chart summarizes the planned effort for the continuation of the NASTRAN program structural analysis. Case 1 used aluminum as the tribeam material; Case 2 will be similar to Case 1, except the tribeam material will be (most likely) graphite/polysulfone. The graphite/polysulfone advanced composite has a service temperature around 180°C, is a thermoplastic, and compatible with anticipated on-orbit fabrication processes.

SPS STRUCTURAL ANALYSIS

- PLANNED EFFORT

- RUN ADDITIONAL CASES

- CASE 2: LIKE CASE 1 EXCEPT COMPOSITES
 - CASE 3: LIKE CASE 1 WITH PRETENSIONING OF X-TENSION BRACES
 - CASE 4: LIKE CASE 2 WITH PRETENSIONING OF X-TENSION BRACES

- RECOMMEND MATERIAL: ALUMINUM OR COMPOSITES
 - DOCUMENT STRESSES AND DEFLECTIONS

- AS TIME PERMITS; ISOLATE ROTARY JOINT AND ANTENNA STRUCTURE AND CONDUCT ANALYSIS



SUMMARY

This chart summarizes the conclusions of System Engineering analyses performed during this quarter of activity.

SUMMARY

- AMORPHOUS SILICON SOLAR CELLS REQUIRE RELATIVELY LOW PROCESS COST COUPLED WITH HIGH EFFICIENCY TO BE COMPETITIVE WITH GaAs
 - BETTER "BET" MAY BE GaAs MULTI-BAND GAP POLYCRYSTAL
- EXCESS SOLAR ARRAY POWER UTILIZATION COULD LEAD TO ECONOMIC "PAY OFF"
- GROUND STORAGE OF SPS ENERGY "MARGINAL" COST EFFECTIVE
- NO SIGNIFICANT ADVANTAGE FOR REFLECTOR ANGLES GREATER THAN 60°
- EOL REFLECTIVITY FOR CONCENTRATOR RAISED TO 0.83 (WAS 0.72) - LOWER RADIATION DEGRADATION ALLOWANCE
- HIGH VOLTAGE dc CONVERTERS REQUIRE ACTIVE THERMAL CONTROL - SWITCHGEAR CAN BE PASSIVELY COOLED
- OVERALL SATELLITE EFFICIENCY DROPPED TO 5.78% FROM 6.06% - REQUIRES ADDITIONAL 500 MEGAWATTS FROM SOLAR ARRAY
- 500 kV ac DEFINED FOR UTILITY INTERFACE
- NASTRAN ANALYSIS PRELIMINARY RESULTS INDICATE LITTLE CHANGE TO STRUCTURES



SOLID STATE
MPTS
ARRAY DESIGN



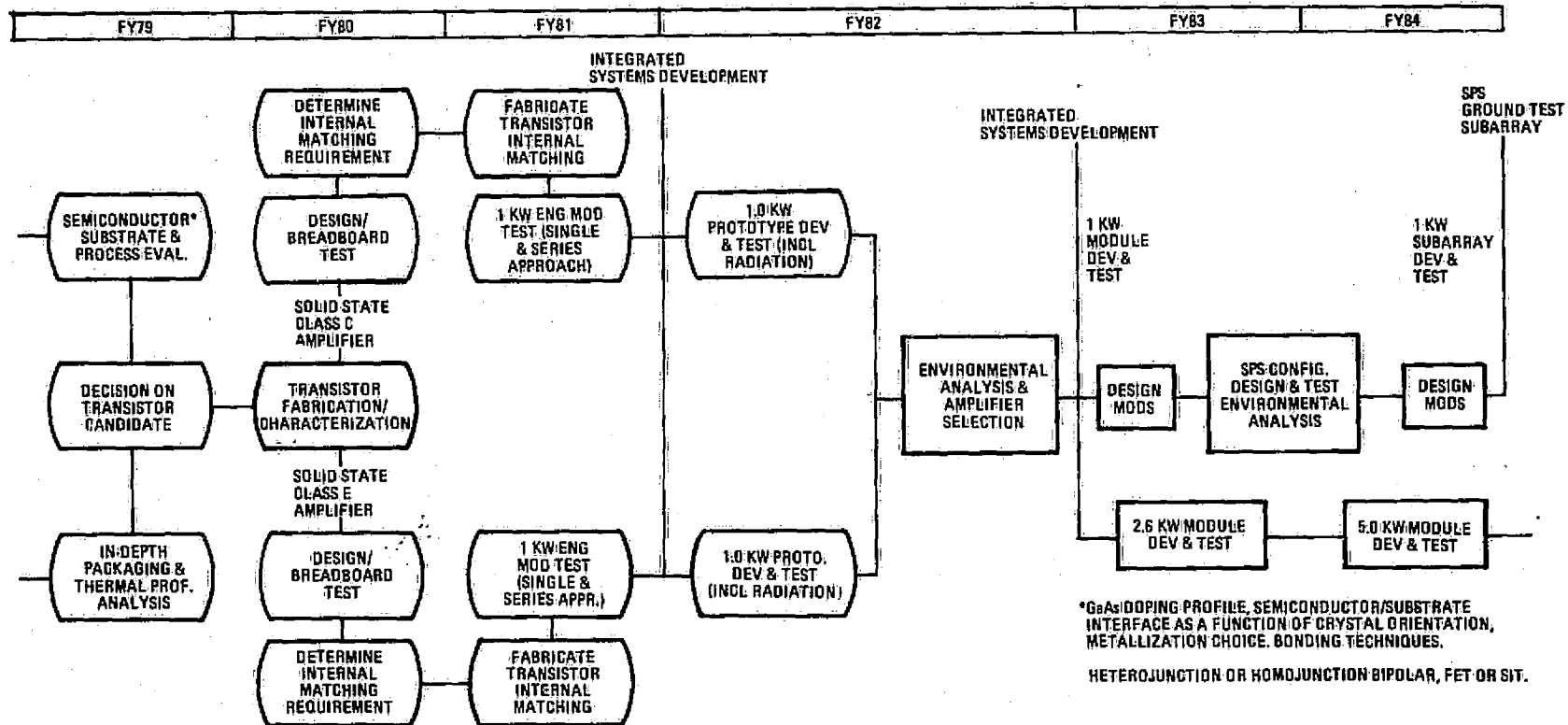
**SOLID STATE DEVELOPMENT SCHEDULE
(TECHNOLOGY VERIFICATION)**

The solid state development schedule is highly dependent upon the transistor candidate decision, the semiconductor substrate and processing evaluation and the packaging and thermal profile analysis.

Present optimization studies indicate that the module development/test and subarray development/test programs will involve a solid state module output power level in the range of one to five kilowatts.

SOLID STATE DEVELOPMENT SCHEDULE (TECHNOLOGY VERIFICATION)

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W. FINNELL NASA MSFC
D. CH'EN R SC
G.D. O'CLOCK SSTSD



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SOLID STATE MPTS DESIGN DRIVERS

Three basic solid state limitations (maximum breakdown voltage, output power and circuit efficiencies) will have a significant impact on the spacecraft weight, array geometry, power distribution system thermal profile and over-all efficiency.

SOLID STATE MPTS DESIGN DRIVERS

DESIGN DRIVER

IMPACT

1. MAXIMUM BREAKDOWN VOLTAGE
(CAN PUT TWO TRANSISTORS IN SERIES
TO INCREASE BREAKDOWN VOLTAGE BUT
THIS WOULD REQUIRE A HIGH DEGREE OF
TRANSISTOR REPRODUCIBILITY & MATCHING
AND COULD IMPACT EFFICIENCY ---WILL NOT
HELP DC-DC CONV. PROBLEM SIGNIFICANTLY)
2. OUTPUT POWER LIMITATIONS
3. CIRCUIT EFFICIENCIES

- COMPLETE REVISION OF POWER DISTRIBUTION SYSTEM
- WEIGHT
- COST
- EFFICIENCY vs LIFETIME

- WEIGHT
- RELIABILITY
- OVER-ALL EFFICIENCY
- THERMAL PROFILE
- ARRAY GEOMETRY

- OVER-ALL EFFICIENCY
- THERMAL PROFILE
- WEIGHT
- RELIABILITY
- NOISE & SPURIOUS
- MATERIAL CANDIDATES (SEMICONDUCTOR & STRUCTURAL)



**SOLID STATE POWER MODULE TRANSISTOR AND
SEMICONDUCTOR MATERIAL CANDIDATES**

Each transistor candidate has electrical performance and physical limits due to material defects and limitations.

SOLID STATE POWER MODULE TRANSISTOR AND
SEMICONDUCTOR MATERIAL CANDIDATES

<u>ITEM</u>	<u>SEMICONDUCTOR MATERIAL CANDIDATES</u>	<u>COMMENTS</u>
BIPOLAR		
HETEROJUNCTION	- GaAs-(GaAl)As - Si-InP - Ge-GaAs	- GOOD LATTICE MATCH, NO SEVERE MATERIAL INTERFACE PROBLEMS. - THERMAL LIMITATIONS - MATERIAL INTERFACE PROBLEMS LIMITING CURRENT GAIN
HOMOJUNCTION	- GaAs	- EFFICIENCY POTENTIAL LOWER THAN HETEROJUNCTION
FET	- GaAs	- SURFACE STATE LIMITED, LOWEST BREAKDOWN VOLTAGE
STATIC INDUCTION TRANSISTOR	- GaAs	- HIGH BREAKDOWN VOLTAGE POTENTIAL, BULK MATERIAL CONDUCTION ADVANTAGES, LOW POWERS AT PRESENT



SOLID STATE AMPLIFIER TRANSISTOR CANDIDATES

Four basic transistor types can be considered as potential candidates for the solid state power module.

SOLID STATE AMPLIFIER TRANSISTOR* CANDIDATES

<u>TRANSISTOR CANDIDATE</u>	<u>ADVANTAGE</u>	<u>DISADVANTAGE</u>
GaAs BIPOLAR	- HIGH BREAKDOWN VOLTAGE (~ 40v)	- SLIGHTLY LOWER POWER & GAIN COMPARED WITH GaAs FET
GaAs FET	- HIGH POWER & GAIN	- LOWEST BREAKDOWN VOLTAGE (~ 25v) - SURFACE EFFECT LIMITATIONS
GaAs STATIC INDUCTION TRANSISTOR	- HIGHEST BREAKDOWN VOLTAGE POTENTIAL (~ 70v)	- OUTPUT POWERS ARE LOW WITH PRESENT DEVICES
HETEROJUNCTION BIPOLAR TRANSISTOR	- HIGHEST EFFICIENCY POTENTIAL - HIGH OUTPUT POWER POTENTIAL	- HIGHEST DEVELOPMENT COSTS

* APPEARS TO BE THE ONLY SOLID STATE DEVICE CAPABLE OF MEETING THE HIGH EFFICIENCY REQUIREMENTS.

SOLID STATE POWER MODULE SEMICONDUCTOR/SUBSTRATE
MATERIAL COMBINATION CANDIDATES

Problems associated with semiconductor/substrate crystal orientation must also be considered along with material limitations.

SAMPLE OF
SOLID STATE POWER MODULE SEMICONDUCTOR/SUBSTRATE
MATERIAL COMBINATION CANDIDATES

<u>SEMICONDUCTOR*</u>	<u>SUBSTRATE</u>	<u>COMMENTS</u>
(111) GaAs	(0001) SAPPHIRE	- SOME STRESS PROBLEMS CAUSING INTERFACIAL DEFECTS. (ROCKWELL ERC SOLAR CELL CANDIDATE)
(111) GaAs	(10 $\bar{1}$ 1) BEO	- REPRODUCIBILITY PROBLEM
(100) GaAs	(11 $\bar{2}$ 2) BEO	- BEST FOR BEO
(111) GaAs	(10 $\bar{1}$ 1) BEO	- DEFECT AND IMPURITY PROBLEMS
(100) GaAs	(110) SPINEL	- SOME DEFECT PROBLEMS
(111) GaAs	(111) SPINEL	- LESS DEFECT PROBLEMS: BEST FOR SPINEL

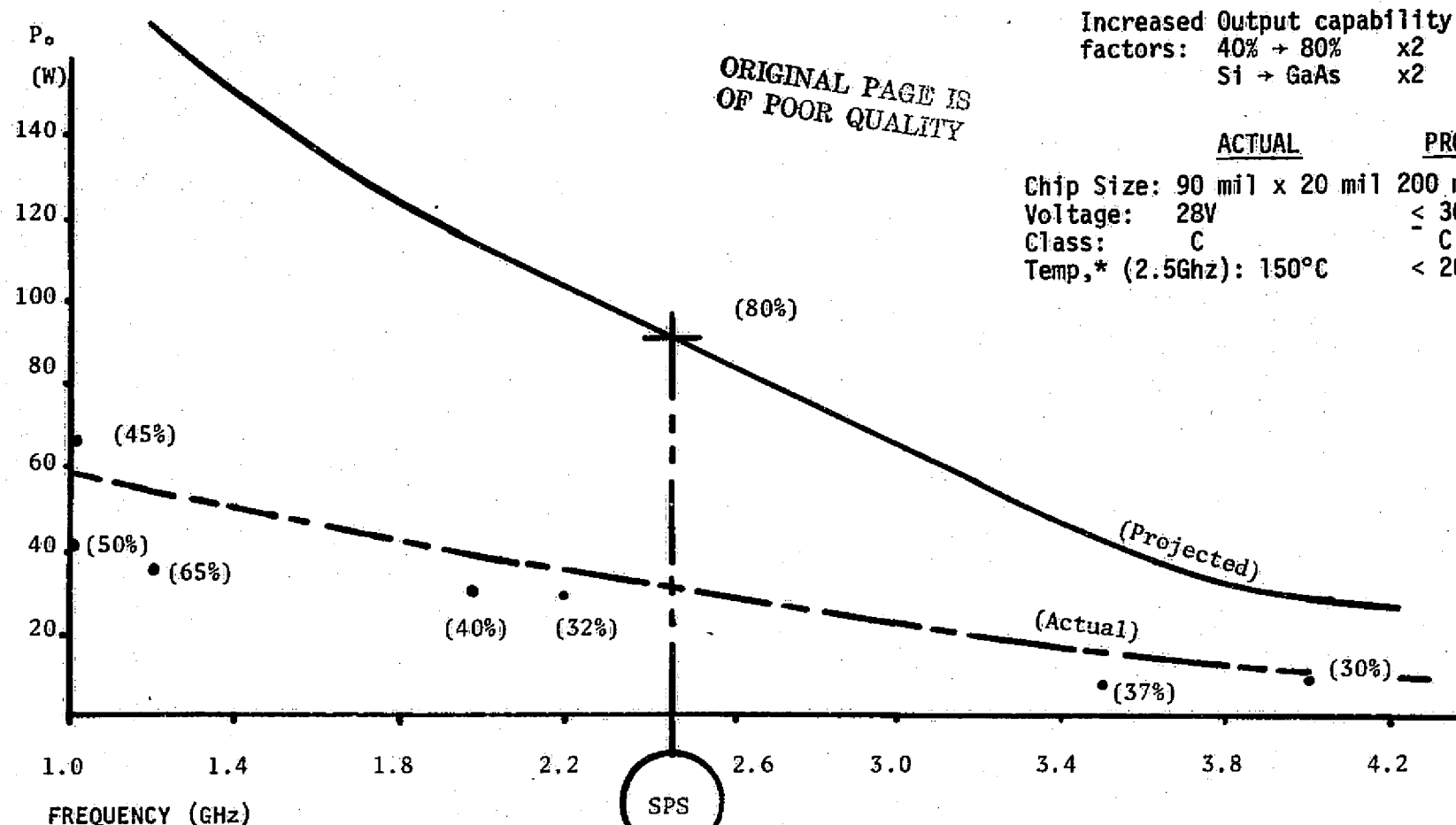
*MANY OF THE CURRENT GaAs FET, HOMOJUNCTION BIPOLAR AND HETEROJUNCTION BIPOLAR DEVICES HAVE BEEN FABRICATED ON (100) GaAs N⁺ SUBSTRATES OR CHROMIUM DOPED SEMI-INSULATING (100) GaAs SUBSTRATES. (111) GaAs APPEARS TO HAVE A DEFECT/IMPURITY PROBLEM SIMILAR TO (111) SILICON.



GaAs BIPOLAR SS AMPLIFIER PROJECTIONS BASED ON
SI BIPOLAR SS AMPLIFIER OUTPUTS AND EFFICIENCIES

Future performance levels (output power and efficiency) for GaAs bipolar transistor candidates can be based on present performance levels of Si bipolar transistors at lower efficiencies. Physical profiles of the future transistor candidates can also be estimated from present size data.

GaAs BIPOLAR SS AMPLIFIER PROJECTIONS BASED ON Si BIPOLAR SS AMPLIFIER OUTPUTS & EFFICIENCIES



*@ 3°C/w(si) 5°C/w (GaAs) 25°C AMB.

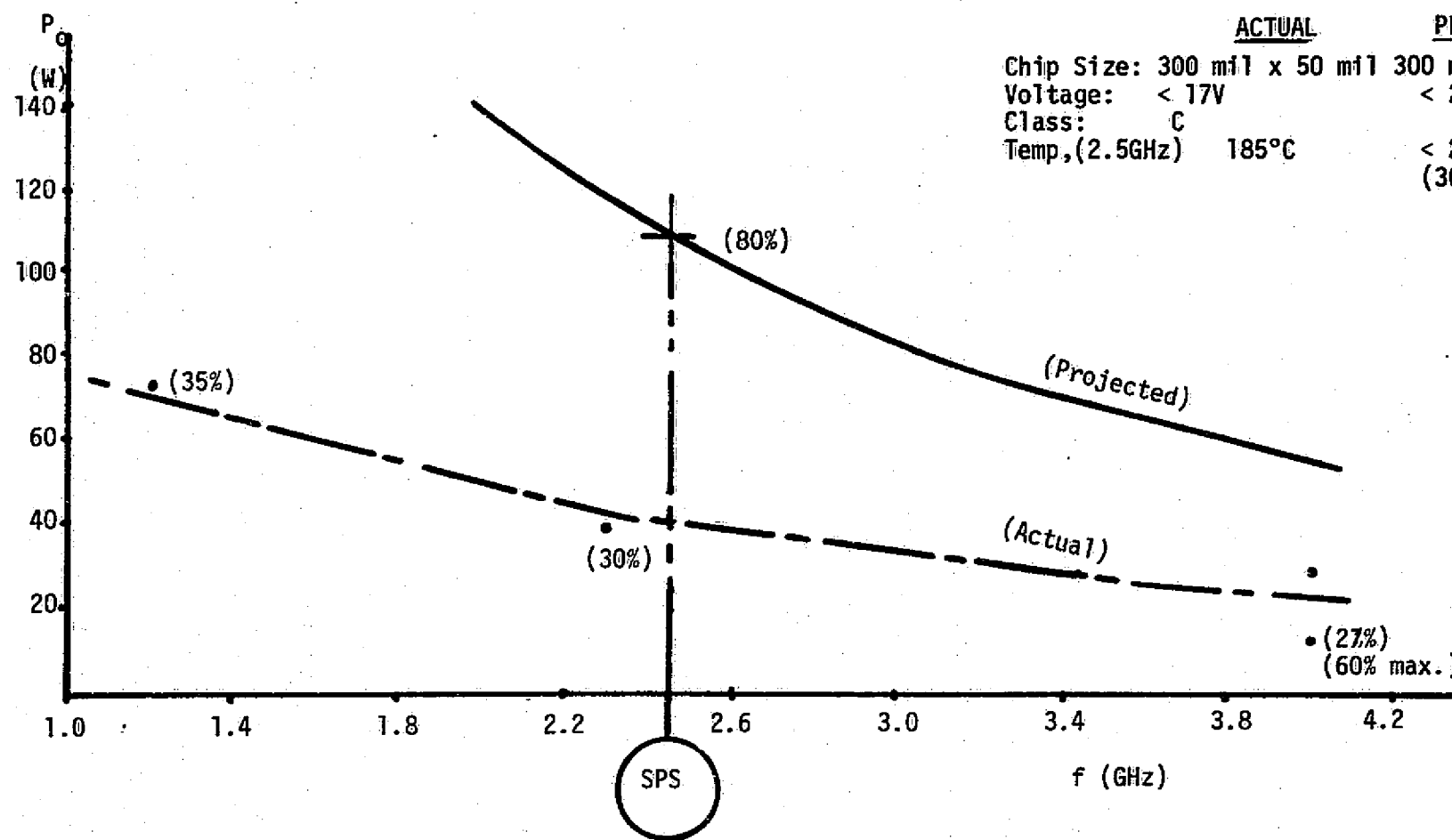


GaAs FET SS AMPLIFIER PROJECTIONS BASED ON
CURRENT GaAs FET AMPLIFIER OUTPUTS AND EFFICIENCIES

Future performance levels (output power and efficiency) GaAs field effect transistors can be based on present performance levels of similar devices at lower efficiencies. Physical profiles of the future transistor candidates can also be estimated from present size data.

GAA's FET SS AMPLIFIER PROJECTIONS BASED ON CURRENT GAA's FET AMPLIFIER OUTPUTS & EFFICIENCIES

Increased output capability factors:
30% → 80% x 2.7



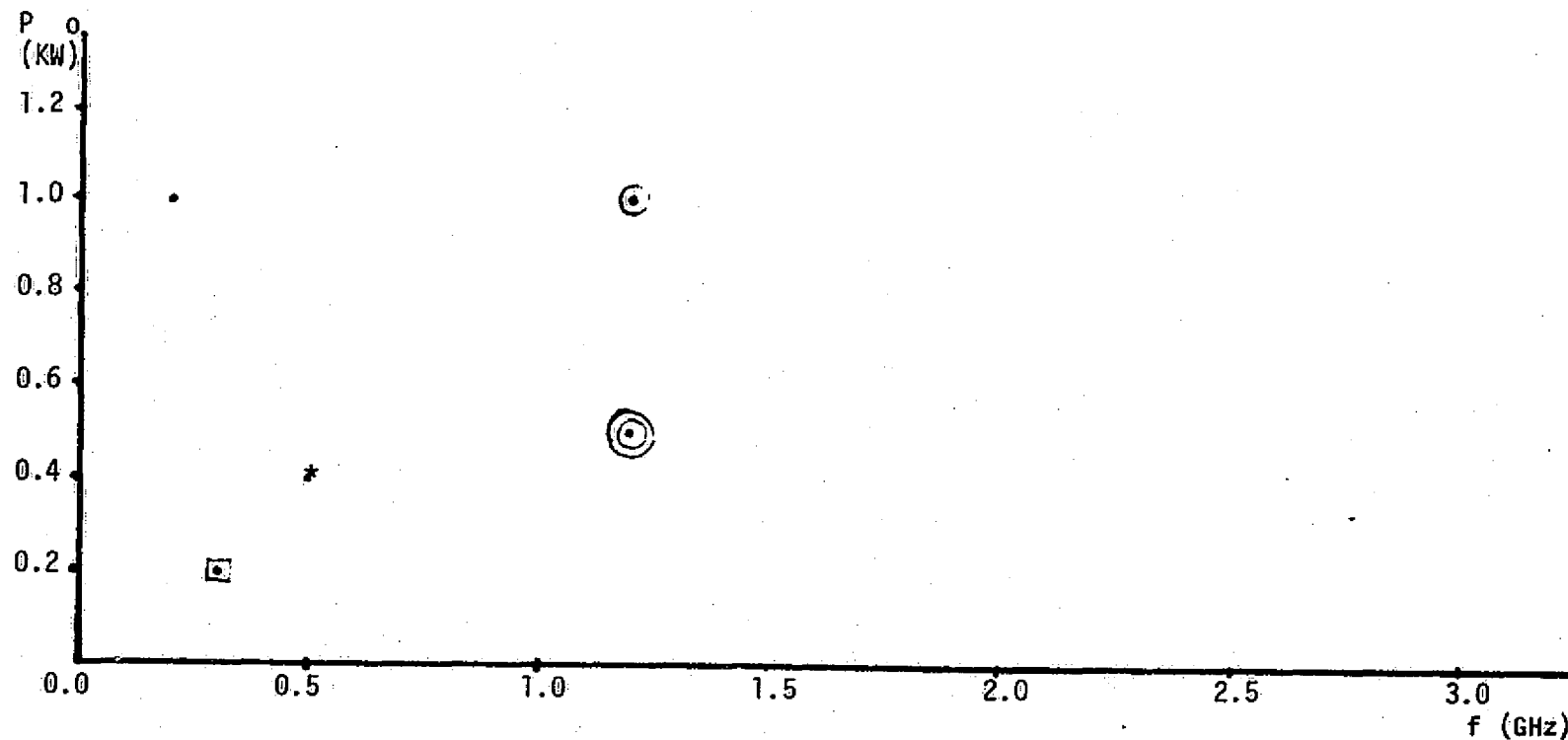
	ACTUAL	PROJECTED
Chip Size:	300 mil x 50 mil	300 mil x 100 mil
Voltage:	< 17V	< 200V
Class:	C	E
Temp, (2.5GHz)	185°C	< 200°C (30°C AMB.)



RESULTS OF PREVIOUS HIGH CW POWER AMPLIFIERS
USING POWER COMBINING TECHNIQUES

Presently, 1 kW solid state power modules have been designed and tested for avionic applications. The efficiencies are two to three times lower than the SPS solid state power module efficiency goal.

RESULTS OF PREVIOUS HIGH CW POWER AMPLIFIER USING POWER COMBINING TECHNIQUES



- .
 - ⊙
 - ⊗
 - *
 - ⊠
- 35% EFFICIENT, SI BIPOLAR, 5-250 W MODULES, 20% BW, 1971
- 35% EFFICIENT, SI BIPOLAR, 12-100 W MODULES, 10% BW, 1972
- 30% EFFICIENT, SI BIPOLAR, 10-75 W MODULES, 25% BW, 1974
- 50% EFFICIENT, SI BIPOLAR, 20-40 W MODULES, 20% BW, 1971
- 50% EFFICIENT, SI BIPOLAR, 2-100 W MODULES, 20% BW, 1975



COMPARISON OF GaAs BIPOLAR AND GaAs FET PROJECTED
PERFORMANCE PARAMETERS

The projected transistor performance parameters can be estimated from the previous performance projections.

COMPARISON OF GaAs BIPOLAR & GaAs FET PROJECTED PERFORMANCE PARAMETERS

ITEM	GaAs BIPOLAR	GaAs FET
. POWER OUTPUT	90W	108W
. EFFICIENCY *	$\geq 78\%$	$\leq 90\%$
. SPURIOUS OUTPUTS BELOW CARRIER	> 50 dB	> 50 dB
. GAIN	20 dB	22 dB
. VOLTAGE †	≤ 40 V	< 25 V
. JUNCTION TEMPERATURE $\left[180^{\circ}\text{C AMBIENT} \right]$ $\left[\theta = 1^{\circ}\text{C/W} \right]$	$< 200^{\circ}\text{C} \left[170^{\circ}\text{C LIMIT} \right]$	$< 200^{\circ}\text{C} \left[170^{\circ}\text{C LIMIT} \right]$
. CLASS ‡	C	E
. MTBF	< 11 YEARS $\left[J \leq 2 \cdot 10^4 \text{ A/CM}^2 \right]$ $\left[T_J = 200^{\circ}\text{C} \right]$	< 12 YEARS $\left[J \leq 2 \cdot 10^4 \text{ A/CM}^2 \right]$ $\left[T_J = 200^{\circ}\text{C} \right]$
. RADIATION HARDNESS ‡		
RADS (Si)		
NEUTRON	$\leq 10^{15}$ N/CM. ²	
. 1 dB COMPRESSION POINT (P ₀)	130W	140W

* TRANSISTORS WILL REQUIRE INTERNAL INPUT/OUTPUT MATCHING NETWORKS.

† HIGH FET SOURCE DRAIN BREAKDOWN VOLTAGE REQUIRES INLAID N⁺ SOURCE - DRAIN.

‡ DEGRADATION IN FALL TIME DUE TO R-C (1-2Ω & 3 - 10PF) FAVORS

CLASS C FOR BIPOLAR AND CLASS E FOR FET.

‡ ABRUPT EMITTER-BASE JUNCTION & OPTIMUM BASE WIDTH WILL INCREASE BIPOLAR HARDNESS.



COMPARISON OF GaAs BIPOLAR AND GaAs FET
PROJECTED PHYSICAL PARAMETERS

The projected transistor physical parameters can be estimated from present transistor physical profiles.

COMPARISON OF GaAs BIPOLAR & GaAs FET PROJECTED PHYSICAL PARAMETERS

ITEM	GaAs BIPOLAR	GaAs FET
• SUBSTRATE MATERIAL	GaAs, SAPPHIRE, BeO OR SPINEL	GaAs, SAPPHIRE, BeO OR SPINEL
• CHIP SIZE	200 MIL X 50 MIL	300 MIL X 100 MIL
• CHIP THICKNESS	8 MIL (THICK GaAs)	10 MIL (THIN GaAs)
• GEOMETRY*	INTERDIGITATED	INTERDIGITATED
• METALLIZATION PROFILE	Cr/Pt/Au, Au/Ge Ti/W/Au, Au/Sn, Au/Zn	AuGe/Pt (THERMAL AGING) Ni/Au/Ge, Cr/Pt/Au, Au/Cr-Pt AL (PERF) Ti/W/Au (BURNOUT)
• EMITTER OR GATE LENGTH	1.5μ	2.0μ (4.5μ CHANNEL)
• EMITTER OR GATE WIDTH	60μ	≤ 5000μ
• JUNCTION	ION IMPLANT	INLAID N ⁺ SOURCE & DRAIN*
• DOPING	N ⁺ 2·10 ¹⁸ CM ⁻³ (3μ) N 10 ¹⁷ CM ⁻³ (5μ)	N ⁺ REGION 3 10 ¹⁸ CM ⁻³ N REGION (0.2μ THICK) 10 ¹⁷ CM ⁻³
• DIE-PACKAGE (IF APPLICABLE)	BeO	BeO
• NUMBER OF INDIVIDUAL CELLS	200 (60μ)	100 (250μ)

* INTERDIGITATED CHOSEN FOR LOWEST r_b' , GOOD FREQUENCY RESPONSE AND OUTPUT POWER AND REASONABLE PROCESSING REQUIREMENTS.

+ 20 250μ WIDE FETs CONNECTED IN PARALLEL ($\lambda/10$ LIMITATION CONSTRAINS INDIVIDUAL GATE WIDTHS.)

* FOR HIGH SOURCE-DRAIN BREAKDOWN VOLTAGE.

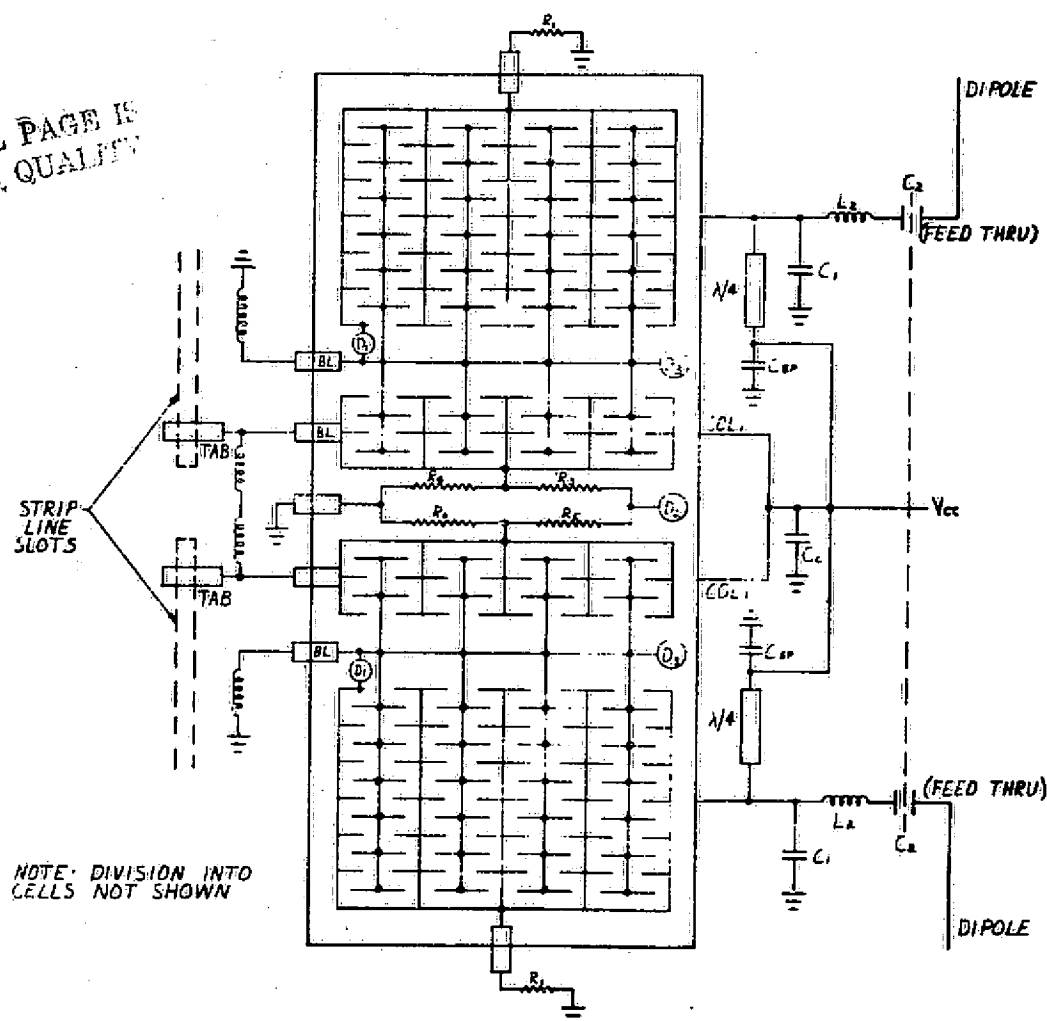


GaAs TRANSISTOR CHIP LAYOUT

The GaAs transistor chip could be configured to contain two high power transistor stages for a push-pull amplifier configuration, low power drive transistors and associated internal matching circuits. One of the primary keys to high efficiency operation will be the performance of the internal transistor matching circuits.

TRANSISTOR CHIP LAYOUT

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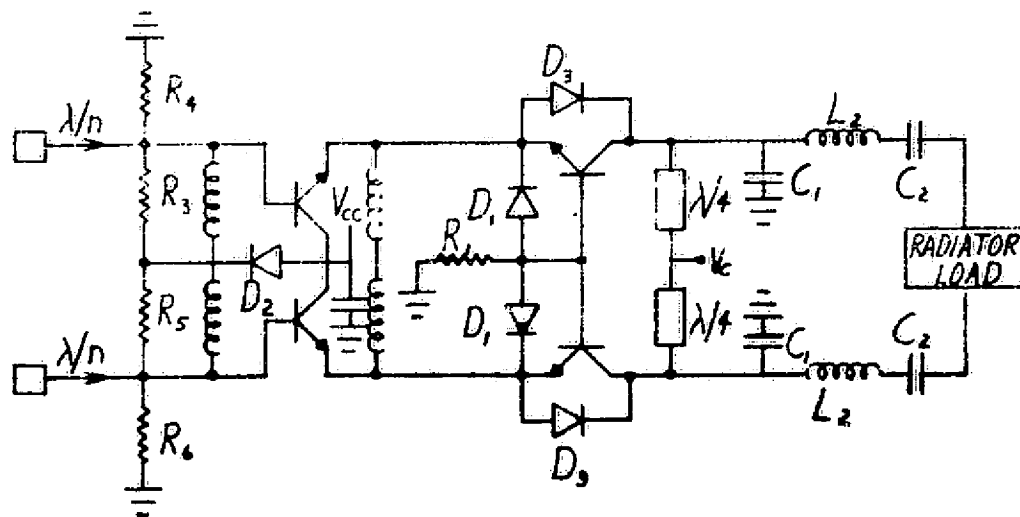


GaAs TRANSISTOR CHIP SCHEMATIC

A common-base push-pull amplifier has been chosen from the standpoints of power output, efficiency and RF stability.

TRANSISTOR CHIP SCHEMATIC

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SPS SOLID STATE POWER MODULE CANDIDATES
USING CONVENTIONAL POWER COMBINING TECHNIQUES

Based on the previous transistor electrical performance and physical profile projections, a wide range of solid state power module options are available. Current optimization estimates indicate that the 1 kW to 5 kW output power range appears to be best for the solid state power module.

SPS SOLID STATE POWER MODULE CANDIDATES
USING CONVENTIONAL POWER COMBINING TECHNIQUES

ITEM	POWER OUTPUT AT 2.45 GHz			
	500W	1KW	10KW	50KW
● BASIC AMPLIFIER CONFIGURATION	115W Single Stage Class C or E ($\leq 90\%$ Efficiency)	236W Push Pull Class C or E ($\leq 86\%$ Efficiency)	247W Push Pull Class C or E ($\leq 79\%$ Efficiency)	260W Push Pull Class C or E ($\leq 78\%$ Efficiency)
● COUPLER CONFIGURATION	5 Way-Radial Line (Fused Silica or Sapphire)	5 Way-Radial Line (Fused Silica or Sapphire)	10-1KW Modules on a 10 Way-Radial Line Coupler (Fused Silica or Sapphire)	12-2.6KW Modules on a 12 Way-Radial Line Coupler stacked with another 12 Modules (Sapphire)
● SUPPLY VOLTAGE	40V	40V	25V	40V
● TRANSISTOR CANDIDATE	GaAs Bipolar	GaAs Bipolar	GaAs FET	GaAs Bipolar
● NUMBER OF INDIVIDUAL SS POWER MODULES	13,586,400	6,793,200	679,320	135,864
● INDIVIDUAL SS POWER SIZE	4" Diam x 2"	4" Diam x 2"	17" Diam x 3"	20" Diam x 8"
● INDIV. SS PWR MOD WGT (with DC/DC Conv.)	2.5 lb.	2.7 lb.	22 lb.	83 lb.
● STATUS	Could be built now with push-pull @ 50%-60% eff. using 10-way combiner	Significant R&D required for transistor	Significant R&D required for circuit eff., combiner loss and transistor output	Significant R&D required for circuit eff., combiner loss, thermal management and transistor output

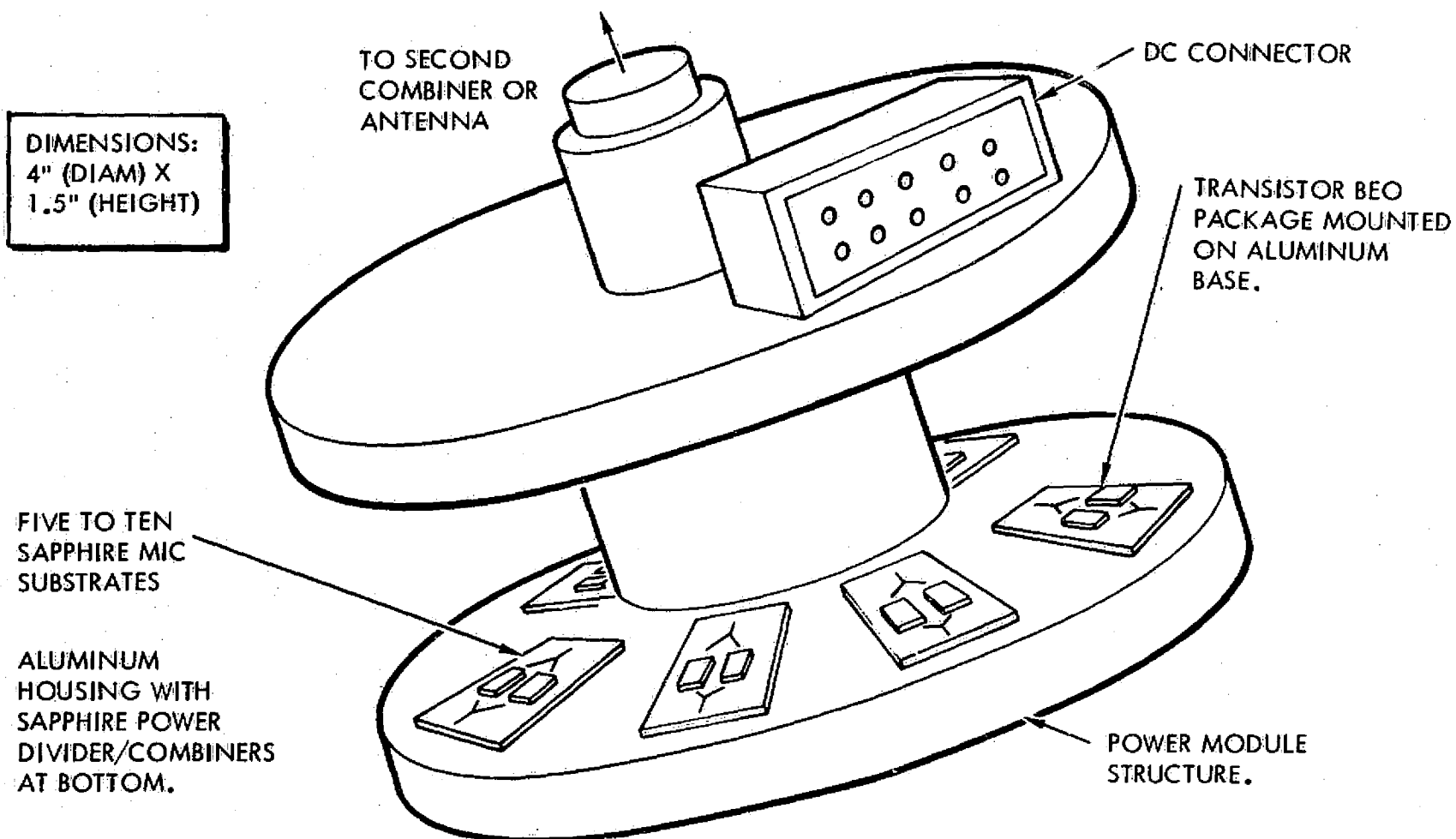
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BASIC 500 W, 1 kW OR 2.6 kW SOLID STATE
POWER MODULE AMPLIFIER CONFIGURATION

A single power module package could provide output powers up to 2.5 kW. The MIC substrates lie flat due to thermal considerations.

BASIC 500 W, 1 KW OR 2.6 KW SOLID STATE POWER MODULE AMPLIFIER CONFIGURATION



POWER MODULE BASE TEMPERATURE: 275°C TO 285°C (GAUSSIAN)
(PRELIMINARY CALCULATIONS) 160°C TO 170°C (UNIFORM-LARGER ARRAY)



PROJECTED SOLID STATE POWER MODULE EFFICIENCY
REQUIREMENTS TO ACHIEVE OVERALL EFFICIENCIES
OF AT LEAST 78%

The projected solid state power module efficiencies will decrease as output power increases due to the effects of additional combiners and module stacking.

**PROJECTED SOLID STATE POWER MODULE EFFICIENCY
REQUIREMENTS TO ACHIEVE OVERALL EFFICIENCIES OF AT LEAST 78%**

ITEM	POWER OUTPUT AT 2.45 GHz			
	<u>500 W</u>	<u>1 KW</u>	<u>10 KW</u>	<u>50 KW</u>
BASIC AMPLIFIER CIRCUIT EFFICIENCY	92%	90%	90%	95%
OUTPUT RADIAL LINE COMBINER EFFICIENCY	95% (0.23DB)	95% (0.23DB)	94% (0.27DB)	93% (0.27DB)
MULTI-MODULE OUTPUT RADIAL LINE COMBINER EFFICIENCY	-	-	93% (0.31DB)	92% (0.03BDB)
STACKING EFFICIENCY	-	-	-	95%
OVERALL EFFICIENCY	90%	85.5%	79%	78%



PROJECTED SOLID STATE POWER MODULE WEIGHTS

Projected solid state power module weights will be heavily influenced by the low voltage/high current power supply.

PROJECTED SOLID STATE POWER MODULE WEIGHTS

ITEM	POWER OUTPUT AT 2.45 GHz			
	500 W	1 KW	10 KW	50KW
RF CIRCUITS AND COMBINERS	0.1LB	0.1LB	1.2LB	2.5LB
HEAT SINK	0.1LB	0.2LB	0.6LB	1.8LB
CONNECTORS	0.2LB	0.3LB	3.0LB	10.4LB
CASE	0.1LB	0.1LB	1.2LB	4.3LB
CONVERTER, REGULATOR CURRENT DISTRIBUTION CONTROL CIRCUITS	2.0LB	2.0LB	16.0LB	64.0LB
TOTAL WEIGHT (INCLUDES LOW VOLTAGE SIDE OF DC/DC CONVERTER)	2.5LB	2.7LB	22.0LB	83.0LB



POWER DISTRIBUTION - SATELLITE

Conventional approaches to solid state power module converter are severely limited by transformer weight and switching speeds.

POWER DISTRIBUTION - SATELLITE

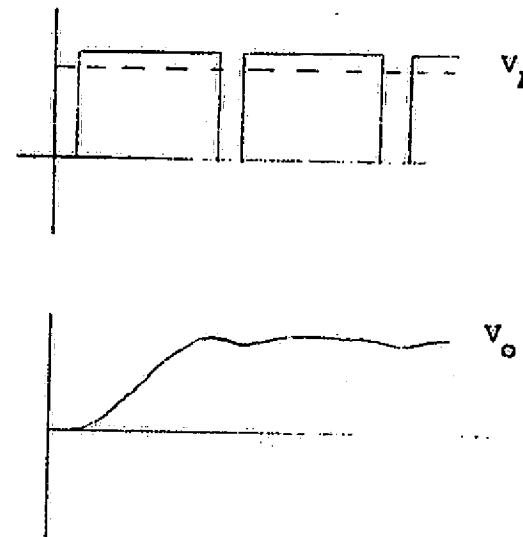
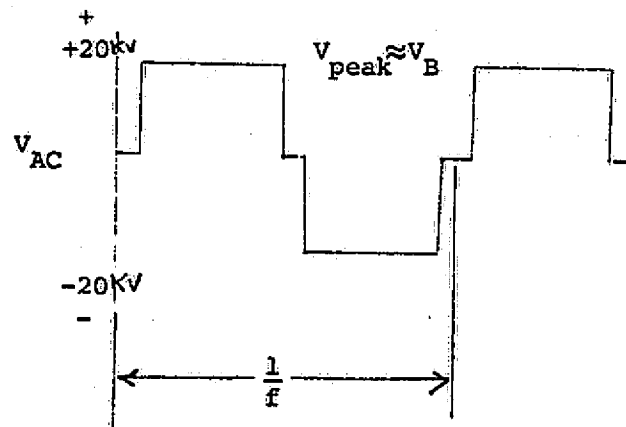
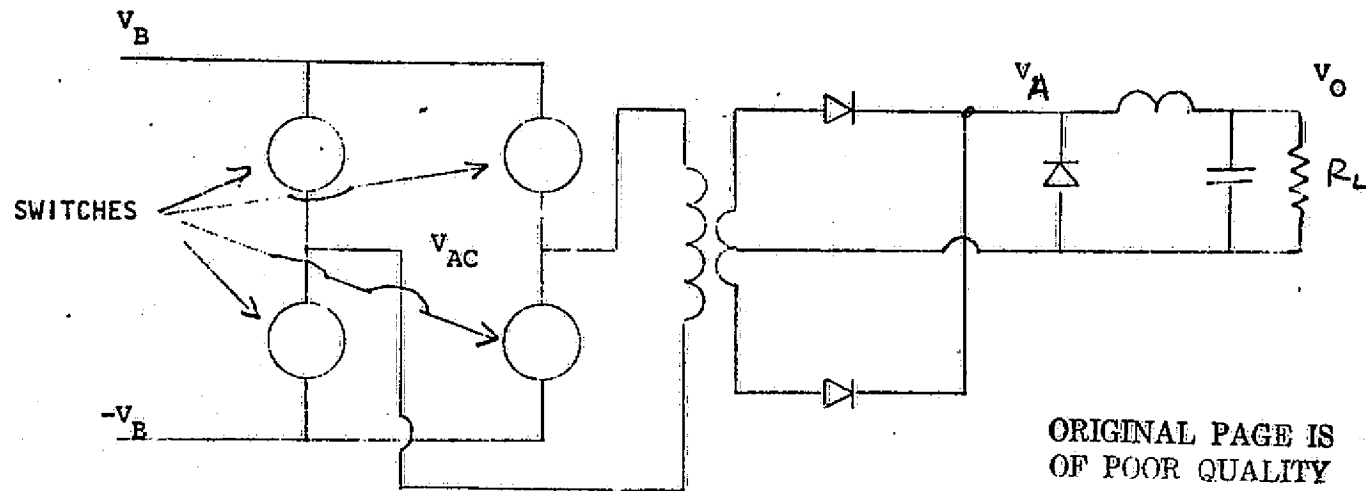
- DC DISTRIBUTION - PANELS THROUGH SLIP RINGS TO RF LOAD
- 20 KV TO 40 KV OPTIMIZES WEIGHT/EFFICIENCY
- 40 KV HIGHLY COMPATIBLE WITH KLYSTRON RF LOAD
- 40 KV TO 40 V DC TO DC CONVERTER POSES DIFFICULTIES WITH RESPECT TO EFFICIENCY WEIGHT, COOLING AND RELIABLE OPERATION
 - CONVENTIONAL DESIGN - EST $\sim 2-4$ KG/KVA, $\eta \cong .8 \rightarrow .85$
 - MODULARIZED N X M DESIGN - EST $.5-1$ KG/KVA, $\eta \cong .9 \rightarrow .95$
(CONVERTER ONLY)



CONVENTIONAL APPROACH—DC TO DC CONVERSION

A conventional dc-to-dc conversion unit consists of a switching network in the primary of the step-down transformer, a rectifier assembly, and various types of filter networks. Also shown in the chart are typical voltage waveforms at various points in the circuit.

CONVENTIONAL APPROACH - DC TO DC CONVERSION

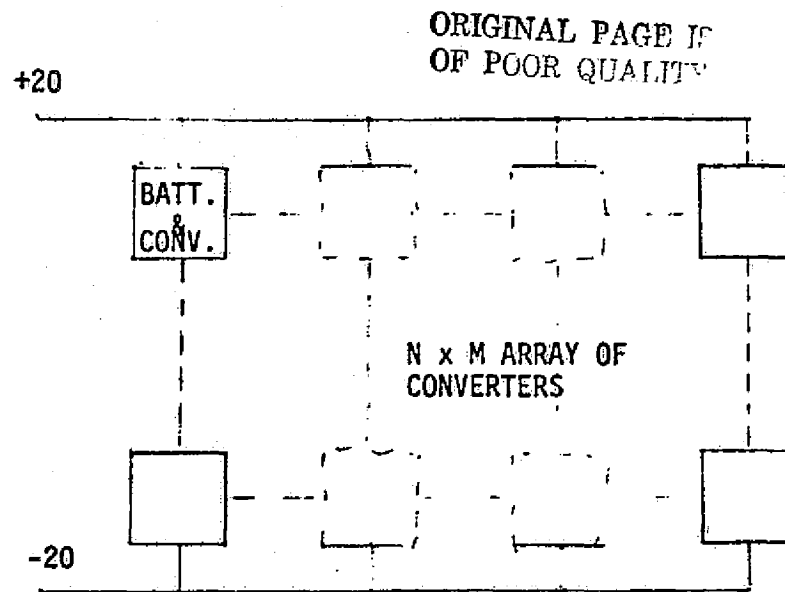


POSSIBLE IMPROVEMENT FOR 40 KV TO 40 V

An alternate approach using converters with smaller step-down ratios is shown using a battery network as a voltage divider.

POSSIBLE IMPROVEMENTS FOR 40 KV TO 40 V

- REDUCE VOLTAGE BY SERIES CONNECTION AND INCORPORATION OF ECLIPSE ENERGY STORAGE BATTERIES
- REDUCE FAILURE MODE (SINGLE POINT FAILURE DISCONNECTS STRING) BY PARALLEL STRINGS



1-2 KW MODULES PROBABLY OPTIMIZE WEIGHT. CAN ALSO USE JPL CONVERTER DESIGN GUIDELINES AT THIS POWER LEVEL.



PRELIMINARY IMPLICATIONS FOR SPS SOLID
STATE POWER MODULE AND MPTS ARRAY
CONFIGURATIONS

The preliminary implications for the SPS solid state power module approach indicate a lower optimum module output power (1 kW - 5 kW) compared with the klystron (50 kW). The preliminary implications also indicate a significant change in the size, weight and complexity of the solid state module power distribution system. Increased complexities and reduced efficiencies associated with the solid state module power distribution system, in the present point design configuration, appear to require an alternate SPS configuration for the solid state approach.

PRELIMINARY IMPLICATIONS FOR SPS SOLID STATE POWER MODULE AND MPTS ARRAY CONFIGURATIONS

SOLID STATE POWER MODULE CONFIGURATION

- 1 KW TO 5 KW POWER MODULE
- HIGH TEMPERATURE (ALLOY) BONDING
- MATCHED SERIES TRANSISTOR PAIRS* (NOT A GOOD IDEA FROM EFFICIENCY STANDPOINT)
- MPTS ARRAY SIZE AND POWER DISTRIBUTION CHANGE
- MICROWAVE POWER DISTRIBUTION SYSTEM MAJOR CHANGES.

DESIGN DRIVER

- POWER DISTRIBUTION DC/DC CONVERTER.
- THERMAL PROFILE
- EFFICIENCY
- LIFE-TIME
- LIFE-TIME
- POWER MODULE & ELECTRONICS TEMPERATURE
- TRANSISTOR BREAKDOWN VOLTAGE

REASONS

- CAPACITANCE LIMITATION ON TRANSFORMER WINDINGS.
- TEMPERATURE LIMITATIONS ON STACKED MODULES.
- LOWER POWER MODULES ARE MORE EFFICIENT
- CONVENTIONAL BONDS WILL FAIL OVER 200°C.
- TRANSISTOR FAILURES TEND TO INCREASE AS BREAKDOWN VOLTAGE IS APPROACHED.
- BASE TEMPERATURES IN EXCESS OF 250°C ARE ANTICIPATED. ~~7~~
- LOW VOLTAGE (<100v) HIGH CURRENT PROBLEM.

*WHAT WE NEED IS A TRANSISTOR, CAPABLE OF DELIVERING 92% EFFICIENCY AT 2.45 GHz, WITH A SIMPLE STRUCTURE, HIGH TEMPERATURE CAPABILITY AND A BREAKDOWN VOLTAGE IN EXCESS OF 300v.

7ELECTRONICS ARE PRIMARY THERMAL DESIGN DRIVER (<100°C).



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SOLID-STATE MASS PROPERTY IMPACTS

	Δ MASS, 10^6 KG	
	<u>MINIMUM</u>	<u>MOST LIKELY</u>
POWER DISTRIBUTION (40 KV TO 40 V CONVERTERS)	4.0	8.0
THERMAL (RADIATORS)	5.5 (150°C)	13.0 (60°C)
SOLAR ARRAY	<u>1.0</u>	<u>1.0</u>
Δ MASS	10.5	22.0
30% GROWTH	<u>3.1</u>	<u>6.6</u>
TOTAL Δ MASS	13.6	28.6

LARGE MASS INCREASES
DRIVE TOWARD NEW
SOLID-STATE CONCEPTS



RECTENNA SYSTEM



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68PD130742X

COMPARISON OF COAXIAL, MICROSTRIP AND
STRIPLINE APPROACHES FOR VARIOUS SYSTEM
DESIGN FACTORS FOR RECTENNA SUBSYSTEM

Rectenna candidates involving coaxial, microstrip and stripline approaches have been proposed for the rectenna panels. Losses, production costs and sensitivity to environment are three of the major concerns that will determine the design choice for the rectenna panels.

COMPARISON OF COAXIAL, MICROSTRIP AND STRIPLINE
APPROACHES FOR VARIOUS SYSTEM DESIGN FACTORS
FOR RECTENNA SUBSYSTEM

<u>INDEX</u>	<u>COST (PRODUCTION)</u>	<u>LOSSES</u>	<u>POWER CAPABILITY</u>	<u>TOLERANCE SENSITIVITY</u>	<u>Q</u>	<u>SUSCEPTIBILITY TO ENVIRONMENT</u>
BEST	MICROSTRIP	COAXIAL	COAXIAL	MICROSTRIP	COAXIAL	COAXIAL
↓	STRIPLINE	STRIPLINE	STRIPLINE	STRIPLINE	STRIPLINE	MICROSTRIP
WORST	COAXIAL	MICROSTRIP	MICROSTRIP	COAXIAL	MICROSTRIP	STRIPLINE

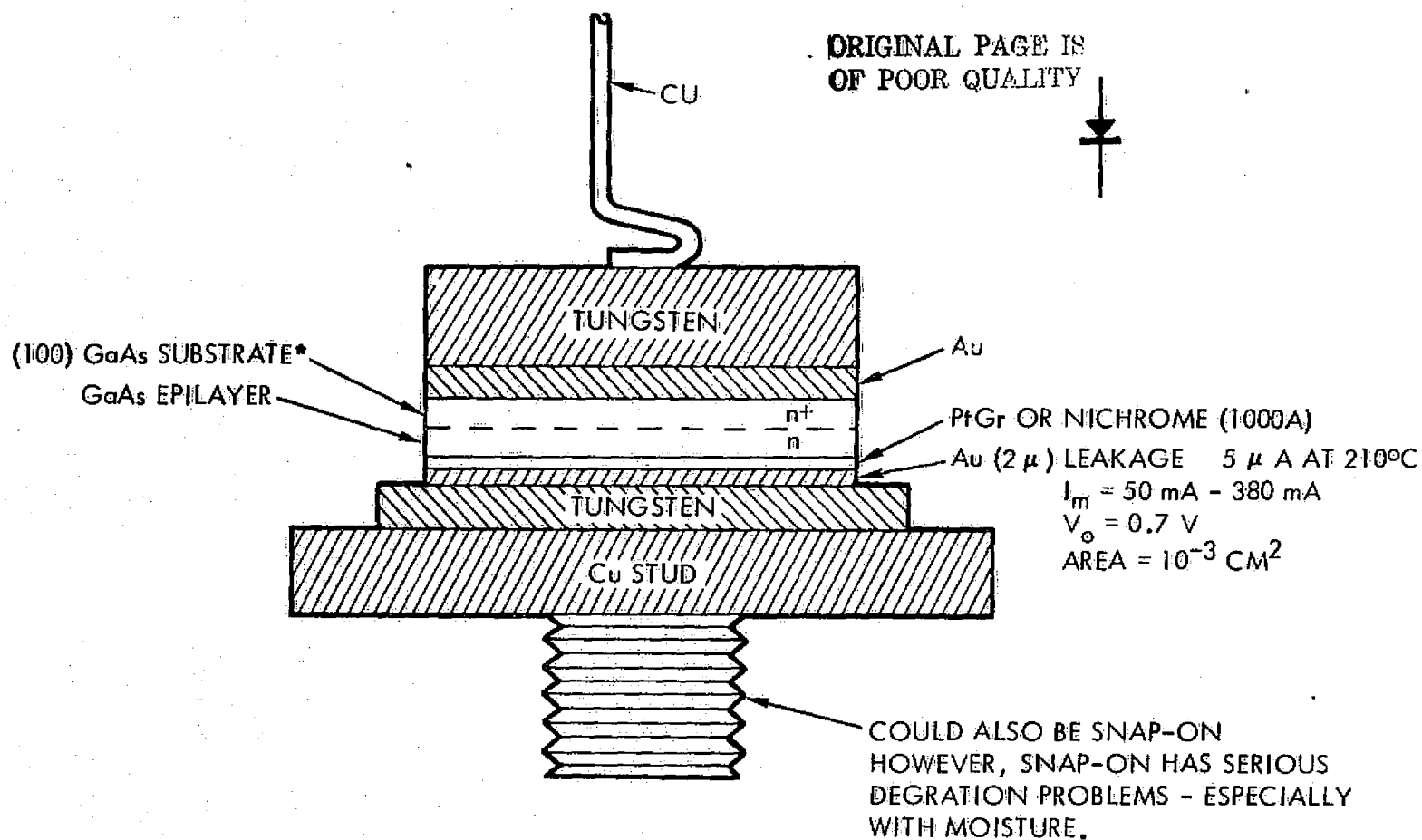


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SPS RECTENNA GaAs SCHOTTKY BARRIER DIODE CANDIDATE

The power handling capabilities of the SPS rectenna Schottky barrier diode will be determined primarily by area. The diode could be either a screw-on or snap-on device. However, without additional high quality welding and/or bonding of the stud to the rectenna, serious degradation problems could occur with the snap-on approach, especially when moisture and temperature cycling are considered.

SPS RECTENNA GaAs SCHOTTKY BARRIER DIODE CANDIDATE



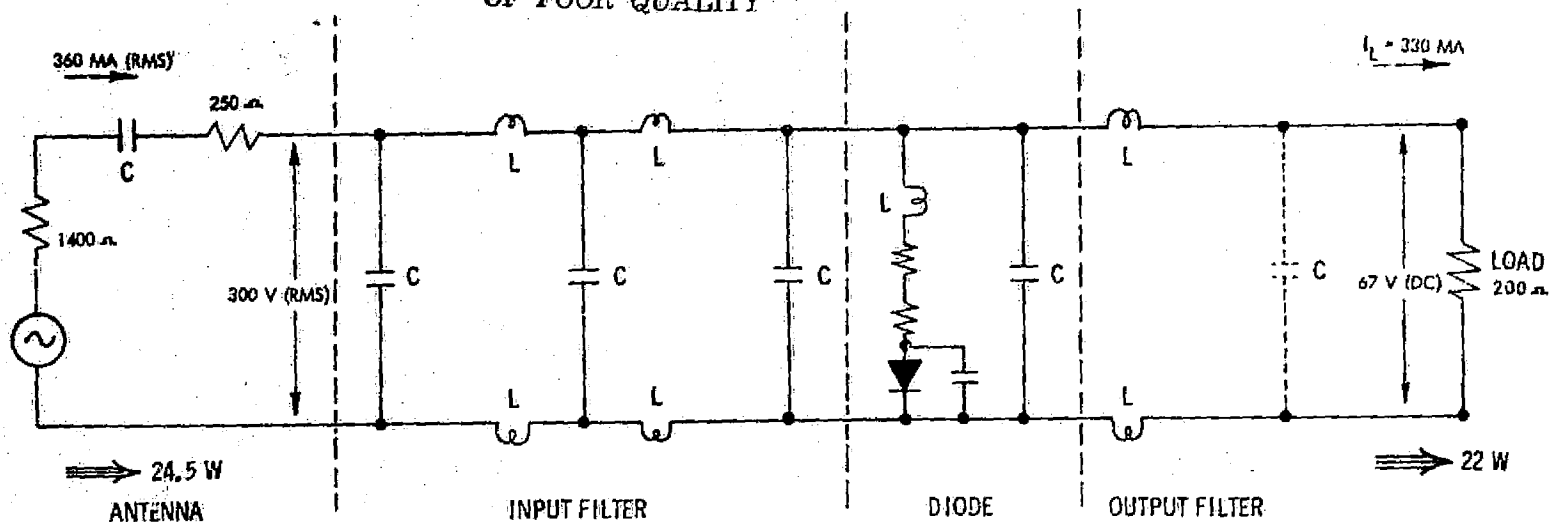
* (111) GaAs IS ALSO A CANDIDATE FOR SCHOTTKY BARRIER DIODES

RECTENNA SUB-PANEL EQUIVALENT CIRCUIT

The rectenna sub-panel equivalent circuit shows the input powers, voltages, currents and impedances that will provide the required rectenna panel output power, voltage and current for a particular panel size.

RECTENNA SUB-PANEL EQUIVALENT CIRCUIT

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FOR 24 KW, 45 KV, 0.33 AMP RECTENNA PANEL

NUMBER OF SERIES RECTENNA ELEMENTS
POWER DENSITY 3.1 KM FROM RECTENNA CENTER
DIODES PER SQUARE METER
PANEL: DIMENSIONS
AREA

~ 1090
 $\sim 136 \text{ W/M}^2$
 ~ 6.1
 $12.24 \text{ M} \times 14.69 \text{ M}$
 179.8 M^2

$\sim 217 \text{ W/M}^2 \text{ } E \approx 300 \text{ V}$



POWER DISTRIBUTION -- RECTENNA

AC vs DC transmission is determined by distance and rate policies.

POWER DISTRIBUTION - RECTENNA

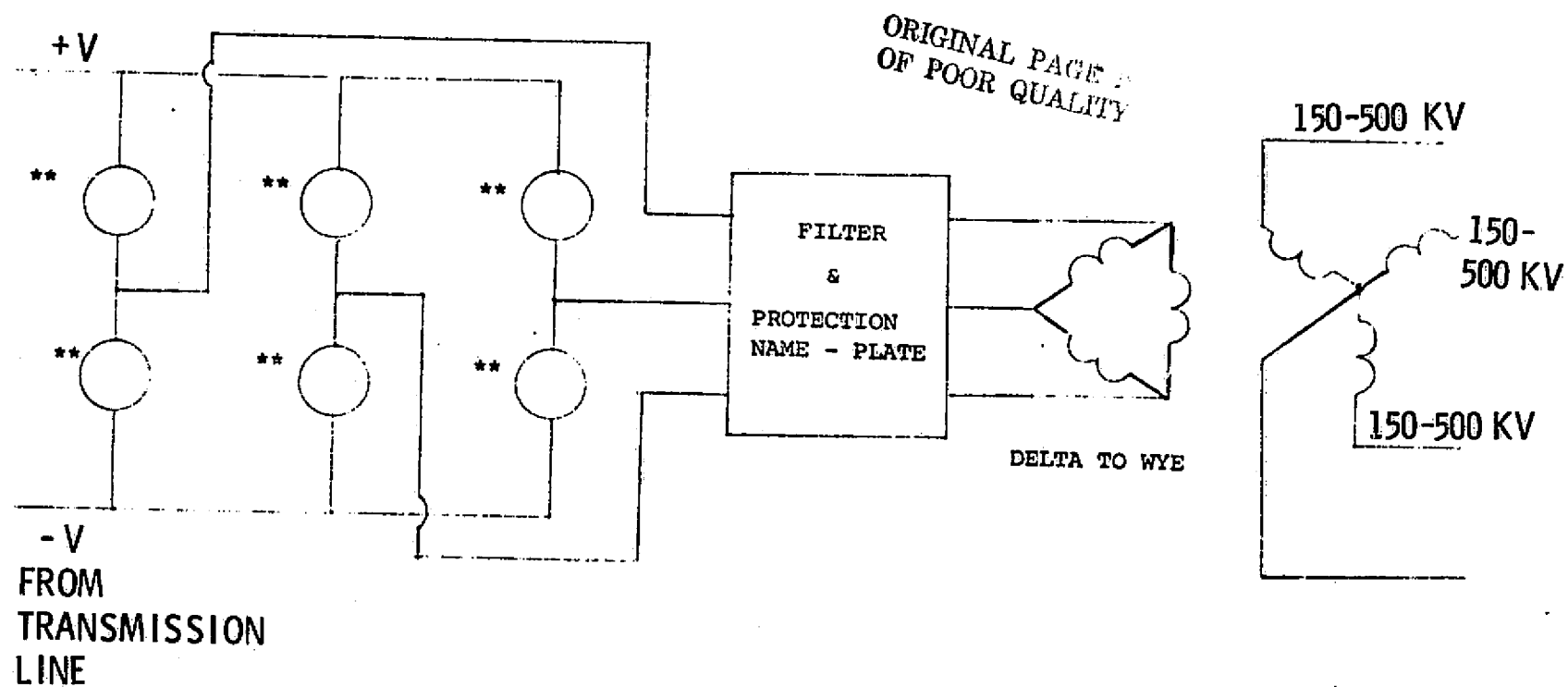
- AC VS DC - DISTANCE FROM LOAD
- DC TO AC CONVERSION
 - TWO WIRE SYSTEM - CONCENTRATED
 - SINE-WAVE SYNTHESIS - DISTRIBUTED
- RECOMMENDATIONS
 - AC DISTANCE LESS THAN 300 MI
 - AC OR DC DISTANCES GREATER THAN 300 MI, LESS THAN 800 MI
 - DC FOR DISTANCES GREATER THAN 800 MI



CONCENTRATED TWO-WIRE SYSTEM AT DISTRIBUTION POINT

A 50% to 75% increase in rectenna land usage is anticipated due to size and number of harmonic filters required.

CONCENTRATED TWO-WIRE SYSTEM



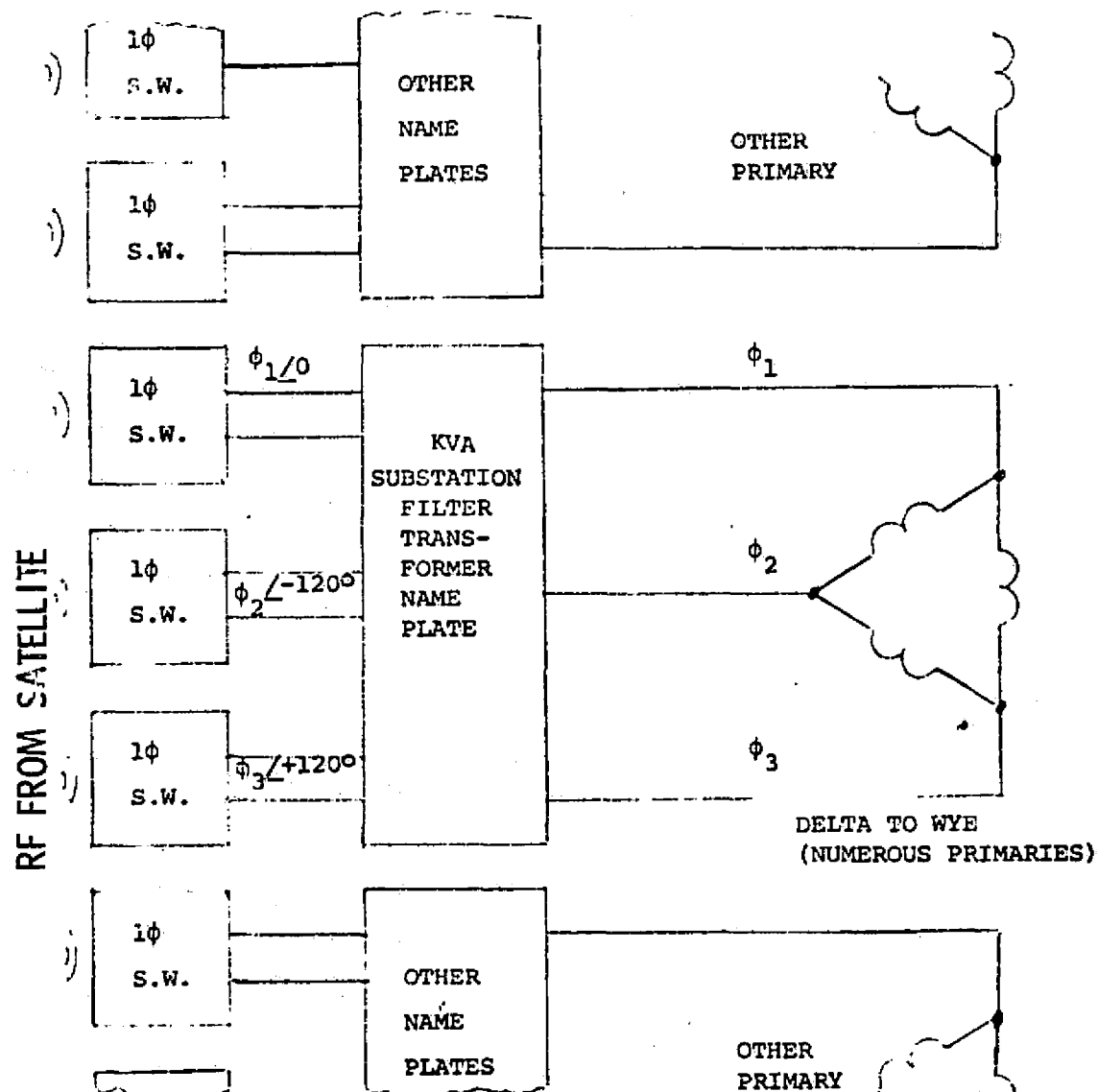
** SWITCH CONTROLS (SCR STACKS OR GAS SWITCHES)



DISTRIBUTED SINE-WAVE SYNTHESIS - RECTENNA/UTILITY INTERFACE

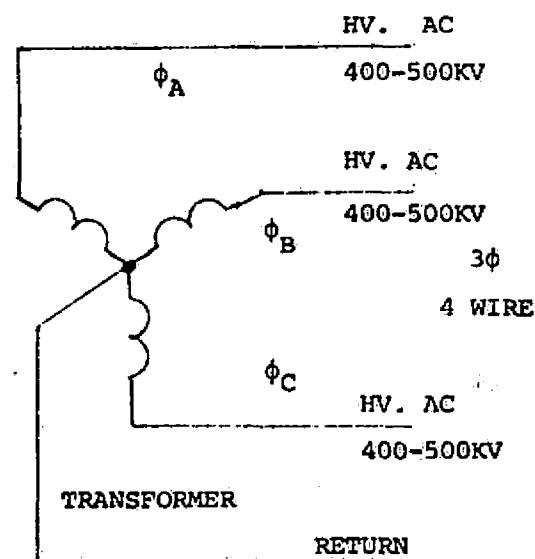
Minimal land usage increase anticipated for this approach. Each harmonic filter can be placed beneath each rectenna panel.

DISTRIBUTED SINE-WAVE SYNTHESIS-RECTENNA/UTILITY INTERFACE



SWITCH GEAR OMITTED FOR CLARITY

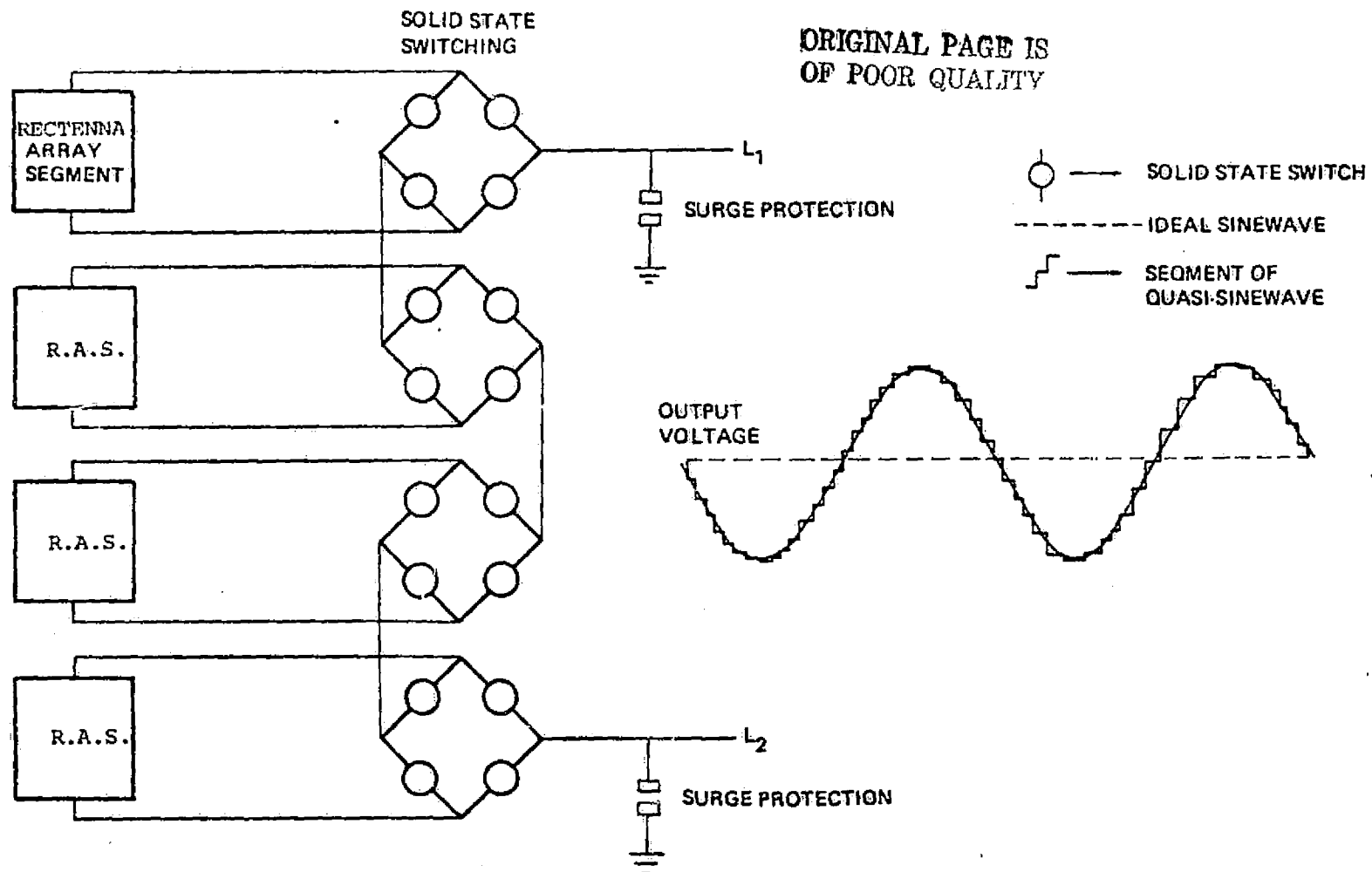
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DEVELOPMENT OF QUASI-SINEWAVE FROM RECTENNA ARRAY SEGMENTS

This chart illustrates how the relatively small dc voltages, derived from the rectified rectenna outputs may be summed to construct a quasi-sinewave. The switching elements are controlled by a dedicated mini/microcomputer as shown in the next chart.

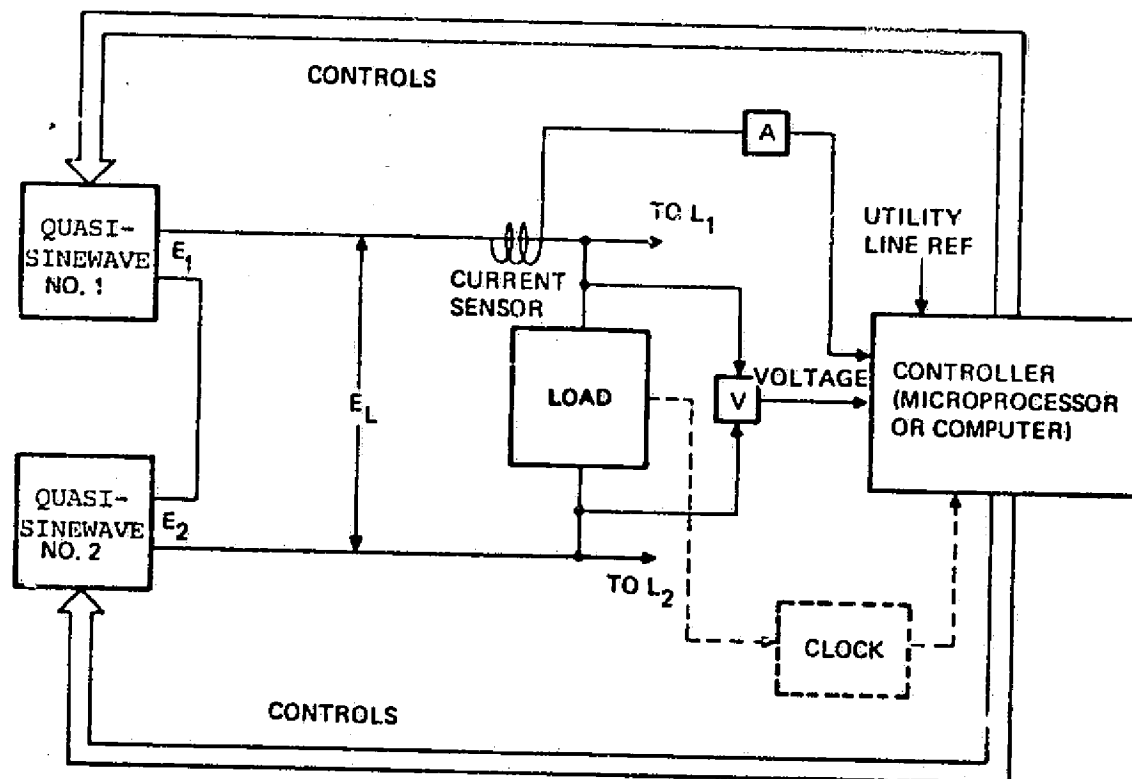
DEVELOPMENT OF QUASI-SINEWAVE FROM RECTENNA ARRAY SEGMENTS



PHASE CONTROL FOR ARRAY SEGMENTS

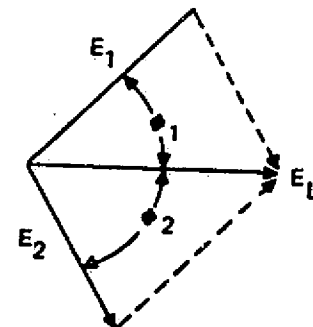
The circuit block diagram shown illustrates how the synthesized quasi-sinewaves are combined under computer control to phase and amplitude control the output (load) ac voltage. The interface presented to the utility user may be established to appear to be a conventional ac generator including the normal phase, voltage and reactive component control paths.

PHASE CONTROL FOR ARRAY SEGMENTS



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E_L = VECTOR SUM
OF $E_1 \angle \phi_1$ AND
 $E_2 \angle \phi_2$



SUMMARY OF SOLID STATE SYSTEM IMPACTS ON SPS

- THE SPS SOLID STATE APPROACH WILL REQUIRE A SIGNIFICANT CHANGE IN THE SPACECRAFT CONFIGURATION.
- THE SPS SOLID STATE DEVICE WILL REQUIRE SIGNIFICANT IMPROVEMENTS IN BONDING AND OHMIC CONTACT PROCESSES THAT WILL WITHSTAND HIGH TEMPERATURES.
- IF THE COMPARISON BETWEEN CLASS C AND CLASS E POWER AMPLIFIER CONFIGURATIONS ARE TO BE MEANINGFUL; A SIGNIFICANT AMOUNT OF WORK AND DECISION MAKING MUST BE DONE AT THE BASIC SEMI-CONDUCTOR/SUBSTRATE MATERIALS, THERMAL/PACKAGING AND SEMI-CONDUCTOR DEVICE LEVEL PRIOR TO ANY AMPLIFIER HARDWARE DEVELOPMENT EFFORT.



SPS MATERIAL AVAILABILITY ANALYSIS



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68PD130660X

PROBLEM

The SPS satellite will require substantial quantities of diverse materials. This pocket study was conducted to ascertain whether a problem existed in the procurement of the various materials, and if so which materials presented potential problems, what was the magnitude of the problem, and what might be some possible solutions. Consequently, the productive capacity of the United States for these materials was determined and the potential impact of SPS satellite construction on this capacity assessed.

PROBLEM

- ANALYSIS OF CURRENT SPS DESIGNS INDICATES THAT AT LEAST 19 BASIC MATERIALS WILL BE REQUIRED IN ITS CONSTRUCTION.
- MANY MATERIALS WILL BE REQUIRED IN RELATIVELY LARGE QUANTITIES.
- ★ WHAT WILL BE THE IMPACT OF SPS MATERIAL DEMANDS ON U.S. PRODUCTION CAPACITY?
- ★ DO SOME MATERIALS PRESENT POTENTIAL AVAILABILITY PROBLEMS?
 - WHICH ONES?
 - WHAT IS THE MAGNITUDE OF THE PROBLEM?
 - WHAT ARE SOME POSSIBLE SOLUTIONS.



GROUND RULES/ASSUMPTIONS/LIMITATIONS

The "productive capacity" of the United States for any given material is elastic and continuously changing. It can be expected to change substantially by the year 2000. Even though some production data are approximations ($\pm 20\%$) they never-the-less would provide a valid basis for a rough-order-of-magnitude (ROM) analysis to ascertain if and where potential problems might exist. In some instances the peak annual production figures over a several year span were used as surrogates for production capacity when those data were unavailable.

The capability of the U.S. to produce the raw materials formed the basis of the analysis. One exception was aluminum because of the diverse sources of bauxite.

The basic analysis was confined to the material requirements of one SPS satellite. However, the results were extrapolated to a construction rate of 4 per year in the analysis and conclusions.

In the case of gallium arsenide and gallium aluminum arsenide, the two gallium requirements were combined as were also those for arsenic. The aluminum requirement was included with that of basic aluminum.

The SPS requirement for sapphire was primarily in the form of ribbon. However, total industrial sapphire production was examined to ascertain the breadth of synthetic sapphire production technology.

Water was identified as the heat transfer medium in the heat pipes. Its availability was judged to be obvious.

Those materials that exceeded 1% of the productive capacity of the U.S. were examined in greater depth.

GROUND RULES/ASSUMPTIONS/LIMITATIONS

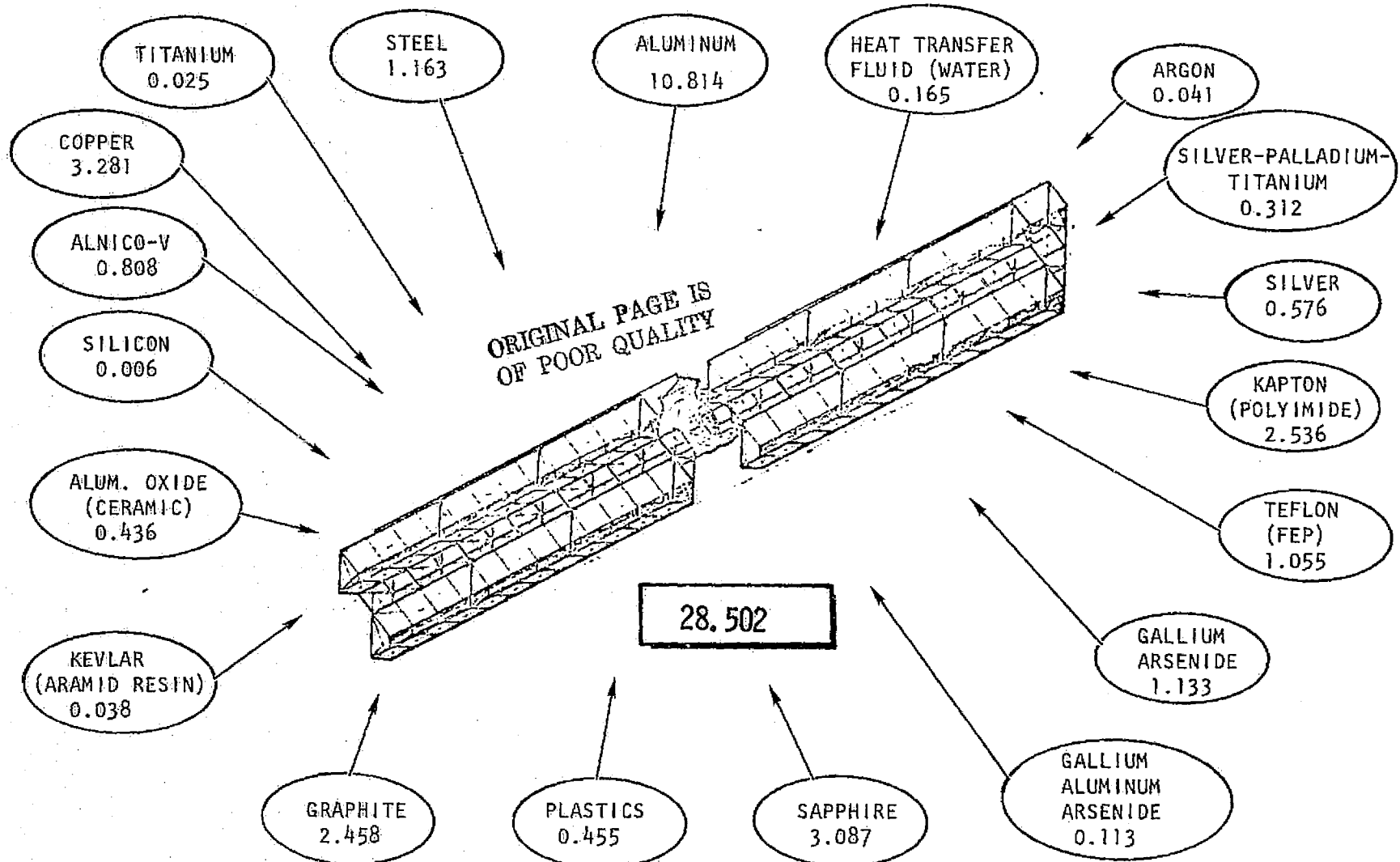
- ROM ANALYSIS
- U.S. BASIC SOURCE OF MATERIALS
- COMPARISON OF MATERIAL DEMAND OF ONE SPS WITH ANNUAL U.S. PRODUCTION OR PRODUCTION CAPACITY.
- PRIMARY EMPHASIS ON AVAILABILITY OF RAW MATERIALS; SECONDARY ON PROCESSING CAPACITY (EXPANDABLE)
- GALLIUM ARSENIDE COMBINED WITH GALLIUM ALUMINUM ARSENIDE.
- SAPPHIRE ASSUMED TO BE IN RIBBON FORM.
- HEAT TRANSFER FLUID IS WATER.



SPS MATERIAL REQUIREMENTS

The accompanying chart shows the basic materials and their quantities (in millions of kilograms) necessary for construction of the SPS satellite. These are the weights used in determining the impact of SPS satellite construction on national productive capacity for these materials.

SPS MATERIAL REQUIREMENTS (MILLIONS OF KILOGRAMS)



SUMMARIZED DATA

The impact of the material requirements of one SPS satellite on the U.S. productive capacity for the respective materials is shown on the accompanying chart. In the cases of cobalt and silver whose annual productivity could present problems, the data also show the material requirements in relation to the government stockpiles.

Those materials whose requirements would exceed 1% of the national productive capacity were the subjects of additional analysis on the subsequent chart.

SUMMARIZED DATA

<u>MATERIAL</u>	<u>REQUIREMENT AS % OF U.S. PRODUCTION</u>
1. ALUMINUM (INCLUDES NOS 5 & 13)	0.24%
2. STEEL	0.001%
3. TITANIUM (INCLUDES No. 17)	0.015%
4. COPPER	0.23%
5. ALNICO-V	
54% IRON	0.0005%
24% COBALT	
AS % of U.S. STOCKPILE	1.0%
AS % OF U.S. CONSUMPTION	2.5%
14% NICKEL	0.73%
8% ALUMINUM	INCLUDED IN NO. 1
6. SILICON	0.005%
7. ALUMINUM OXIDE (FROM BAUXITE)	0.022%
8. KEVLAR/RESIN (ARAMID)	1.7%
9. GRAPHITE (SYNTHETIC + NATURAL)	0.94%
10. PLASTICS	0.003%

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<u>MATERIAL</u>	<u>REQUIREMENT AS % OF U.S. PRODUCTION</u>
11. SAPPHIRE (SYNTHETIC)	
INDUSTRIAL	3400%
RIBBON	97,000%
12. GALLIUM ALUMINUM ARSENIDE	
13. GALLIUM ARSENIDE	
GALLIUM	4000%
ARSENIC	3.6%
ALUMINUM	INCLUDED IN NO. 1
14. TEFLON (FEP)	40%
FLUORINE	0.49%
15. KAPTON (POLYAMIDE)	140%
16. SILVER (INCLUDES NO. 17)	
ANNUAL PRODUCTION	82%
STOCKPILE	4.5%
17. SILVER-PALLADIUM-TITANIUM	
SILVER	96.6%
PALLADIUM	1.7%
TITANIUM	1.7%
U.S.	3000%
WORLD	11.0%
INCLUDED IN NO. 3	
18. ARGON	0.16%
19. HEAT TRANSFER FLUID (WATER)	-



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ANALYSIS OF POTENTIAL PROBLEM MATERIALS

This chart shows those materials whose requirements by 1 SPS would exceed 1% of the current U.S. national productive capacity. The associated comments describe the status of the material's anticipated availability.

A production rate of 4 SPS satellites per year would exacerbate possible material production problems. However, the twenty-plus years prior to the construction of the first SPS satellite (~2000) provides ample time for either expansion of problem material production capacity or the development of substitute materials that would be more readily available and/or more efficient. Most of the plastic materials shown hadn't been developed twenty years ago. Consequently, these or superior materials that would be developed in the ensuing years would actually be used in construction of the SPS satellite, so that this analysis may be viewed as a "worst-case analysis".

ANALYSIS OF POTENTIAL - PROBLEM MATERIALS

1. COBALT : NO U.S. MINING - ALL IMPORTED - OVER 70% FROM ZAIRE. U.S. GOVERNMENT STOCKPILE COULD SUPPLY SPS REQUIREMENTS.
2. KEVLAR : DUPONT ARAMID FIBER. PRODUCTIVE CAPACITY IS BEING EXPANDED. SHOULD NOT PRESENT SUBSTANTIAL PROBLEM.
3. SAPPHIRE : RAW MATERIAL Al_2O_3 PLENTIFUL. REQUIRES LARGE AMOUNTS OF ELECTRIC ENERGY. PRODUCTION APPEARS READILY EXPANDABLE.
4. GALLIUM : ALCOA STUDY* PROJECTS POTENTIAL 1995 GA PRODUCTION CAPABILITY IN U.S. AT 2.6 TIMES 1 SPS SATELLITE REQUIREMENT.
5. ARSENIC : U.S. PRODUCTION CURRENTLY AT HALF OF CAPACITY. PRODUCTION SLACK COULD SATISFY SPS DEMAND.
6. TEFLON : RAW MATERIALS PRESENT NO PROBLEM. PRODUCTION FACILITIES WOULD NEED TO BE EXPANDED. DUPONT'S PATENTS EXPIRING. COMPETITION LIKELY.
7. KAPTON : DUPONT POLYAMIDE. RAW MATERIALS AVAILABLE. PRODUCTION FACILITIES WOULD NEED TO BE EXPANDED.
8. SILVER : ANNUAL PRODUCTION VARIES CONSIDERABLY, BUT SPS WOULD REQUIRE MAJOR PORTION OF PRODUCTION UNLESS WITHDRAWN FROM STOCKPILE.
9. PALLADIUM : ALTHOUGH ONLY A SMALL QUANTITY IS REQUIRED BY SPS, IT VASTLY EXCEEDS U.S. PRODUCTION. MAJOR SUPPLIER IS USSR. U.S. STOCKPILE WOULD BE SIGNIFICANTLY IMPACTED (-14%).

*SURVEY OF AVAILABILITY AND ECONOMICAL EXTRACTABILITY OF GALLIUM FROM EARTH RESOURCES.
ALCOA, 1 OCTOBER 1976



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CONCLUSIONS

While construction of one SPS would not present major material problems, construction of 120 would. At a construction rate of 4/year, requirements for palladium - which is primarily obtained from the USSR, with South Africa as a lesser secondary source - would almost equal 50% of current world production. While the requirements for silver would also approximate 50% of world production, the silver supply is vastly more expandable than the palladium supply. Curtailment of cobalt supplies from Zaire would necessitate development of substitutes for the Alnico V.

Consequently, possible substitutes for Alnico V, silver and palladium should be investigated.

Extrapolation of Alcoa study projections to 2000 indicates that sufficient gallium could be available from annual U.S. Bauxite processing for 4 SPS's per year.

CONCLUSIONS

1. CONSTRUCTION OF FIRST SPS WOULD NOT POSE MAJOR MATERIAL PROBLEMS.
2. CONSTRUCTION RATE OF 4 PER YEAR WOULD REQUIRE SIGNIFICANT EXPANSION OF US PRODUCTION AND/OR IMPORTS OF SEVERAL KEY MATERIALS.
3. PRODUCTION FACILITIES WOULD NEED TO BE EXPANDED FOR:
 - KEVLAR
 - TEFLON
 - KAPTON
 - GALLIUM
 - SAPPHIRE
4. U.S. GOVERNMENT STOCKPILES AND/OR FOREIGN SOURCES WOULD NEED TO BE TAPPED FOR:
 - COBALT
 - SILVER
 - PALLADIUM
5. A SUBSTITUTE MATERIAL SHOULD BE SOUGHT FOR PALLADIUM. CONSTRUCTION RATE OF 4/YEAR WOULD CONSUME APPROXIMATELY HALF OF ANNUAL USSR PRODUCTION OR 3 TIMES SOUTH AFRICAN PRODUCTION.



KEY DATA SOURCES

The accompanying list indicates key sources of data for this analysis. Several other sources were contacted and consulted without acquisition of significant data. These sources are not included. In almost all instances, the data used were verified by reference to a secondary source.

KEY DATA SOURCES

1. THE WORLD ALMANAC - 1978
2. STATISTICAL ABSTRACTS OF THE UNITED STATES - 1976
3. MINERAL FACTS AND PROBLEMS (1970) U.S. DEPT. OF INTERIOR
4. UNITED STATES MINERAL RESOURCES, U.S. DEPT. OF INTERIOR (1973)
5. CHEMICAL INFORMATION SERVICE S.R.I.
6. SOCIETY OF THE PLASTICS INDUSTRY
7. TYCO LABORATORIES, INC. - SAPHIKON DIVISION
8. UNION CARBIDE CORP. - ELECTRONICS DIVISION
9. UCLA REFERENCE LIBRARY
10. CHEMICAL ENGINEERING
11. LIBRARY OF CONGRESS
12. AVIATION WEEK & SPACE TECHNOLOGY
13. CHEMPLAST INC.
14. ALUMINUM COMPANY OF AMERICA REPORT
15. MODERN PLASTICS



ELECTRIC COTV TRIP-TIME
OPTIMIZATION ANALYSIS



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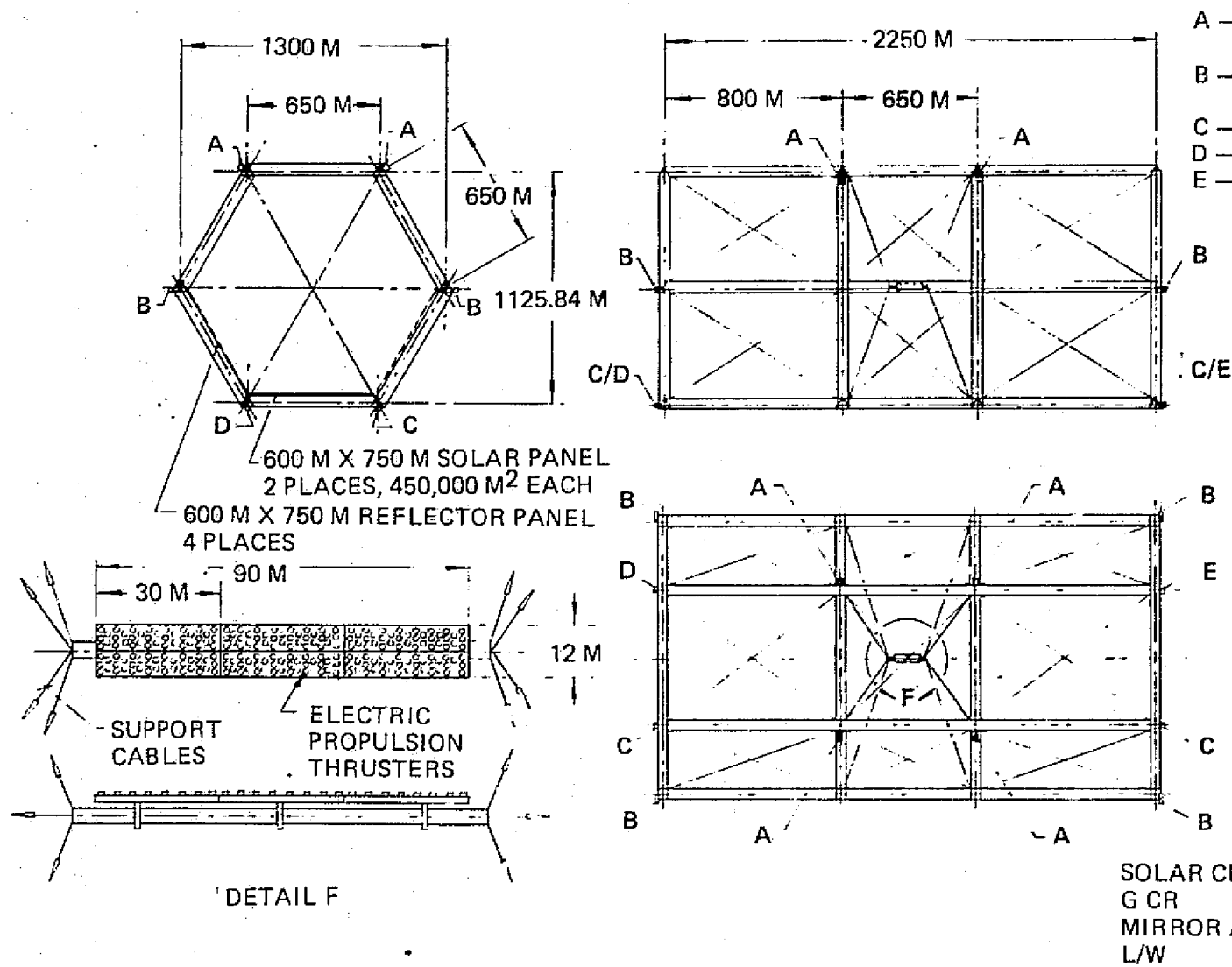
ELECTRIC COTV TRIP-TIME OPTIMIZATION ANALYSIS

An analysis has been conducted to define an approach for comparing electric COTV's which have differing LEO-to-GEO trip times on a \$/kg-of-payload basis. The "recipe" and ingredients along with results are presented in the following charts. Later results should include variations and refinements on any major parameter, especially on electric engine sizes, thrust levels and specific impulses.

ELECTRIC OTV CONCEPT

The electric OTV concept shown is based upon a rigid design which can accommodate two "standard" solar blanket areas of 600 meters by 750 meters from the MSFC/Rockwell baseline satellite concept. The commonality of the structural configuration and construction processes with the satellite and microwave antenna design is to be noted. Since the thrust levels will be very low (as compared to chemical stages), the engines and power processing units are cable-suspended to allow for easy c.g. adjustment and to minimize the rotary joint size requirements. Preliminary analysis show that erosion of the structure in the path of the exhaust will be very small. Due to the very high velocities of the ions, a small exhaust cone angle is predicted, and the design reflects the spacing required to avoid impact on the solar cells. Payload attach platforms are located so that loading/unloading operations can be conducted from "outside" the light weight structure. Other design features are noted on the chart.

ELECTRIC OTV CONCEPT



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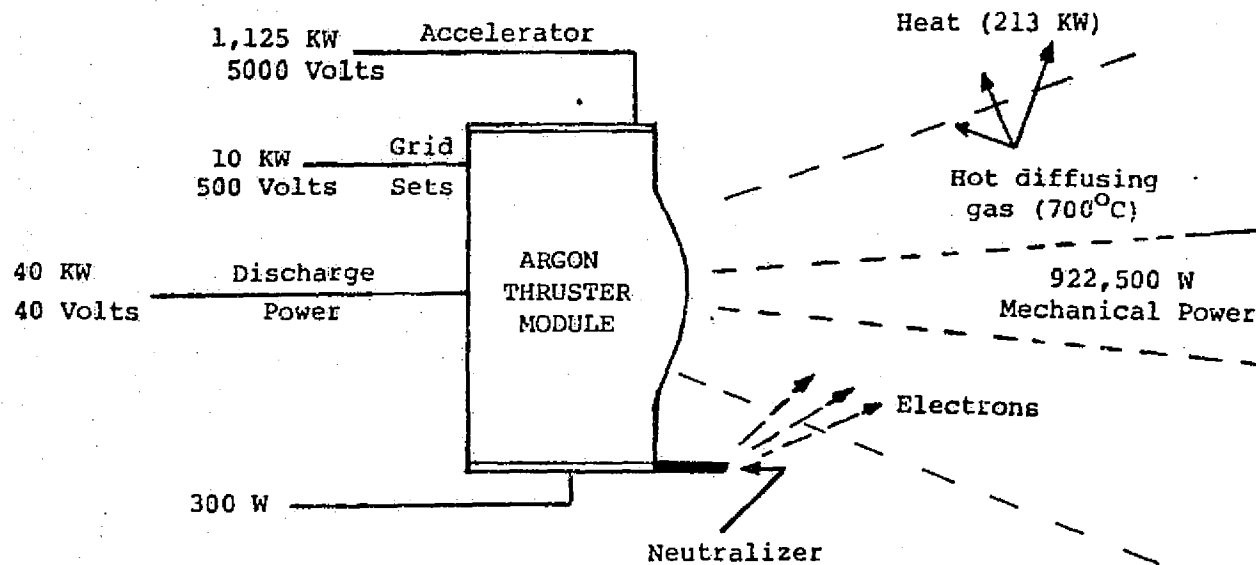
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ARGON ION ELECTRICAL THRUSTER

The electric thruster chosen for this analysis is shown on the accompanying figure with pertinent design and performance characteristics. Approximately 1.2 megawatts of electrical power must be delivered to drive each thruster unit.

ARGON ION ELECTRICAL THRUSTER



- THRUSTER DIAMETER (CM) 100
- THRUST (N) 13.02
- SPECIFIC IMPULSE (SEC) 13,000
- PROPELLANT FLOW RATE (KG/SEC) 10.213×10^{-5}



SIZING THE ELECTRIC COTV - SYSTEM EFFICIENCY

Having fixed the solar blanket area and concentration ratio, an efficiency chain is developed to define the power which can be delivered to the thrusters. This process is depicted with efficiency assumptions noted. Since the trip-time comparisons will be on 180-days LEO-to-GEO transfer or less, the seasonal effects are slightly higher than those for an operational satellite at GEO. The total power delivered is 327 megawatts which will accommodate 273 thrusters which have been reduced to 270 (6 units of 45 thrusters each) payload packaging considerations. The estimated self-annealing capabilities of GaAlAs cells will provide - on the average - 85% performance, resulting in an average effective thrust from 230 thrusters throughout the transfer between LEO and GEO, e.g., 2994.6 N.

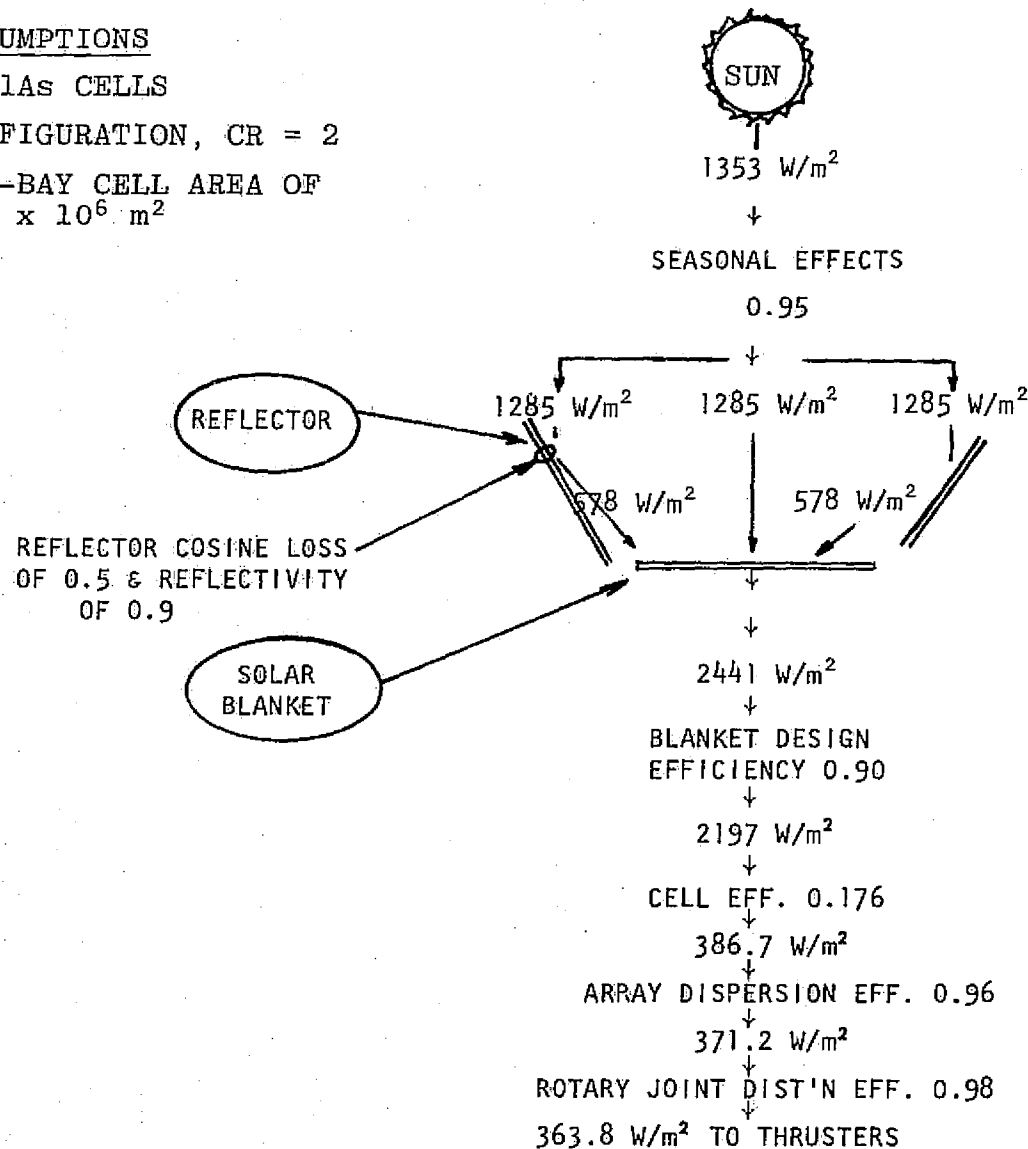
SIZING THE ELECTRIC COTV—SYSTEM EFFICIENCY

ASSUMPTIONS

GaAlAs CELLS

CONFIGURATION, CR = 2

TWO-BAY CELL AREA OF
 $0.9 \times 10^6 \text{ m}^2$



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$$\frac{363.8 \text{ W/m} \times 0.9 \times 10^6 \text{ m}^2}{327 \times 10^6 \text{ W}}$$

AT 1.2 MW/THRUSTER, THIS WILL
 PROVIDE POWER FOR 273 THRUSTER
 MODULES

PAYLOAD PACKAGING ACCOMMODATES
 270 THRUSTER MODULES (E.G.,
 6 UNITS OF 45 THRUSTER MOD-
 ULES/UNIT)



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BASIC EQUATIONS USED IN ANALYSIS

These basic equations are presented to give the reviewer data upon which to check succeeding calculations. Note that the ΔV of 4,508 m/sec is applicable to an equatorial departure orbit at 300 nautical miles. For departures from inclined orbits, the Edelbaum equations are suggested. The calculation of initial COTV mass in LEO, M_1 , was modified slightly to account for ACS propellant use and will be discussed on the next chart.

BASIC EQUATIONS USED IN ANALYSIS

THRUSTER PROPELLANT FLOW RATE

$$\dot{m} = \frac{T}{g I_{sp}}$$

$$\dot{m} = \frac{13.02}{(9.8065)(13,000)}$$

$$\dot{m} = 10.213 \times 10^{-5}$$

ELECTRIC COTV GROSS WEIGHT IN LEO

$$M_p = \text{MASS OF PROPELLANT (LEO-TO-GEO)}$$

$$M_f = \text{MASS REMAINING IN GEO AFTER EXPENDING PROPELLANT } M_p$$

$$M_i = \text{INITIAL COTV MASS IN LEO}$$

$$M_p = M_f \left(\frac{\Delta V}{e g I_{sp}} - 1 \right) \quad \text{WHERE } \Delta V = 4,508 \text{ m/sec (NO PLANE CHANGE)}$$

$$M_p = 0.03606 M_f$$

$$M_i = M_p + M_f = 28.73 M_p$$



SIZING THE ELECTRIC COTV - PAYLOAD MASS CAPABILITIES

By "freezing" the electric COTV size and non-propulsive subsystems, trip time variations are introduced by varying the payload to change the thrust-to-weight relationships. From computer data, the following LEO-to-GEO trip times and thruster burn times were established.

LEO-TO-GEO TRANSFER

Total Trip Times (Days)	Thruster Burn Times (Days)
30	20.8
60	47.0
90	73.2
120	99.4
150	125.7
180	151.8

With these data, one can compute the LEO-to-GEO argon propellant requirements and multiply by 0.2 to yield tankage and line masses needed to calculate GEO-to-LEO propulsive requirements. The return trip-time results which correlate with the above LEO-to-GEO transfers are as follows:

GEO-TO-LEO TRANSFER

Total Trip Times (Days)	Thruster Burn Times (Days)
21.1	14.0
21.3	14.2
21.6	14.4
21.8	14.6
22.2	14.9
22.4	15.1

Minor adjustments were made to the gross weights (i.e., from ~10,000 to ~20,000 kg) to account for expended ACS propellants during the transfers. The weight growth margins are reflected in the propellant mass calculations since they had been added to the non-variable COTV masses.

SIZING THE ELECTRIC COTV - PAYLOAD MASS CAPABILITIES

NON-VARIABLE COTV MASSES (KG)

STRUCTURES AND SUPPORTS	252,000
SOLAR BLANKETS	226,800
REFLECTORS	25,200
THRUSTER MODULES	32,400
ROTARY JOINT	6,540
PWR DISTRIB. & CONTROL	46,500
IMS	11,400
ACS HARDWARE (ALL)	10,800
ACS PROPELLANT - LEO	10,800
	622,440
+30% GROWTH MARGIN	186,730
	809,170

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TRIP-TIME VARIABLE MASSES (KG)	LEO-TO-GEO TRIP TIMES					
	30 DAYS	60 DAYS	90 DAYS	120 DAYS	150 DAYS	180 DAYS
LEO-TO-GEO ARGON PROPELLANT	42,210	95,390	148,560	201,740	255,110	308,080
GEO-TO-LEO ARGON PROPELLANT	28,460	28,880	29,300	29,720	30,140	30,560
ARGON TANKAGE/LINES	14,130	24,860	35,570	46,290	57,050	67,730
ACS FLIGHT PROPELLANT	5,400	10,800	16,200	21,600	27,000	32,400
SUBTOTAL	90,200	159,930	229,630	299,350	369,300	438,770
NON-VARIABLE COTV MASS	809,170	809,170	809,170	809,170	809,170	809,170
ELECTRIC COTV MASS	899,370	969,100	1,038,800	1,108,520	1,178,470	1,247,940
GW IN LEO	1,221,740	2,751,620	4,281,230	5,811,110	7,346,460	8,870,310
PAYLOAD CAPABILITY	322,370	1,782,520	3,242,430	4,702,590	6,167,990	7,622,370



ASSUMPTIONS AFFECTING COTV TRIP-TIME COMPARISONS

The numbers shown for each assumption are not "hard" in the sense of being fully justifiable and the reviewer is encouraged to introduce his own where discrepancies appear. The COTV operations cost variable is introduced to account for the slightly higher degree of activity at the LEO base for the shorter trip time concepts, and is not to be taken as the cost of LEO base operations. COTV turnaround times were based on total trip times plus assumed delays per trip and loading/unloading operations times.

ASSUMPTIONS AFFECTING COTV TRIP-TIME COST COMPARISONS

HLLV PAYLOAD COSTS TO LEO = \$30/KG PAYLOAD
HLLV PAYLOAD INTEGRATION PENALTY OF 10%
HLLV ADDITIONAL PAYLOAD INTEGRATION PENALTY OF 20% FOR PROPELLANT
CONTAINMENT
COTV RESUPPLY PROPELLANT COSTS AVERAGE \$1/KG
COTV THRUSTER GRIDS REPLACED AFTER 4,000 HOURS BURN TIME
COTV THRUSTER GRIDS WEIGH 4 KG/GRID AND COST \$500/GRID
COTV "LIFE" IS DEFINED AS 100% REPLACEABLE AND IS BASED ON COTV
FLIGHT TIMES USING 360-DAY YEARS
COTV OPERATIONS COST VARIABLE IS \$200,000 FOR EACH FLIGHT TURNAROUND
COTV INITIAL ON-ORBIT COST IS $\$150 \times 10^6$
SATELLITE INVESTMENT AT $\$5 \times 10^9$
DISCOUNT RATE IS 7.5%
COTV TURNAROUND TIMES AS LISTED:

LEO-TO-GEO TRIP TIMES

30 DAYS
60 DAYS
90 DAYS
120 DAYS
150 DAYS
180 DAYS

TURNAROUND TIMES

57.6 DAYS
94.1 DAYS
130.6 DAYS
160.8 DAYS
203.9 DAYS
240.4 DAYS



APPORTIONED RESUPPLY AND OPERATIONS COST/KG OF COTV PAYLOAD

An example calculation is shown for the 180-day LEO-to-GEO trip time case with its up payload capability of 7,622,370 kg to demonstrate how costs are apportioned on a \$/kg payload basis. The results for all LEO-to-GEO trip-time cases are also presented and summed. Note that no apportionment has yet been made for the initial/replacement cost of the vehicle. This will be considered in the material to follow.

APPORTIONED RESUPPLY AND OPERATIONS COST/KG OF COTV PAYLOAD

EXAMPLE CALCULATION

180-DAY LEO-TO-GEO TRIP TIME CASE - PAYLOAD = 7,622,370

RESUPPLY:

HLLV OPERATIONS COSTS

- ALL PROPELLANTS (385,080 KG) × 1.1 (PAYLOAD INTEGRATION)
× 1.2 (CONTAINMENT) × \$30/KG (LAUNCH TO LEO) = \$15,249,170
- GRID MASS REPLACEMENTS (4 KG/GRID × 270 GRIDS × 1.3 GROWTH)
× (166.9 BURN DAYS × 24 HRS/DAY ÷ 4,000 HRS) × 1.1 (P/L) × \$30/KG = $\frac{46,400}{\$15,295,570}$
= \$2.007/KG PL

MATERIALS/PROPELLANT COSTS

- PROPELLANT MASS (385,080) × \$1/KG = \$385,080
- THRUSTER MODULE REPLACEMENT GRIDS = $\frac{135,190}{\$520,270}$
= \$0.068/KG PL

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SPACE OPERATIONS:

TURNAROUND COSTS

- AT \$200,000 PER FLIGHT, DIVIDED BY PAYLOAD = \$0.026/KG PL

ALL TRIP-TIME CASES

	LEO-TO-GEO TRIP TIMES					
	30 DAYS	60 DAYS	90 DAYS	120 DAYS	150 DAYS	180 DAYS
RESUPPLY - HLLV OPERATIONS	\$11.099	\$3.322	\$2.550	\$2.255	\$2.101	\$2.007
- MATERIALS/PROP.	\$ 0.367	\$0.111	\$0.086	\$0.076	\$0.071	\$0.068
SPACE OPERATIONS	\$ 0.620	\$0.112	\$0.062	\$0.043	\$0.032	\$0.026
TOTALS	\$12.086	\$3.545	\$2.698	\$2.374	\$2.204	\$2.101



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ELECTRIC COTV FLEET SIZES AND PROGRAM BUYS

The definition of vehicle "life" was stated in the assumptions as requiring 100% replaceability. An example is given here assuming that vehicle life is limited to 5 years of flight time. For the 180-day LEO-to-GEO trip-time case, 5 years times 360 days/year divided by 202.4 flight days per trip yields an average vehicle life of 8.8933 flights. From this data, program buys can be computed and are shown. Also from the data provided, fleet size calculations can be made for each trip-time case. Note that a 10-year "life" would halve the program buy requirements but would not alter the fleet size demands.

ELECTRIC COTV FLEET SIZES AND PROGRAM BUYS

EXAMPLE CALCULATION FOR 180-DAY LEO-TO-GEO TRIP TIME

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- LIFE OF VEHICLE IS 8.8933 FLIGHTS

DURING THE VEHICLE LIFE, IT WILL TRANSPORT $8.8933 \times 7,622,370 \text{ KG} = 67,788,020 \text{ KG}$. THE PROGRAM REQUIREMENTS ARE 120 SATELLITES AT $40 \times 10^6 \text{ KG}$ EACH DIVIDED BY 67,788,020 KG YIELDS THE REQUIRED PROGRAM BUY OF 71 VEHICLES

- ASSUMING THAT A SINGLE SATELLITE MASS OF $40 \times 10^6 \text{ KG}$ MUST BE DELIVERED DURING A 90-DAY INCREMENT, THEN THE FLEET SIZE REQUIREMENT IS 90 DAYS DIVIDED BY TURNAROUND TIME OF 240 DAYS TIMES THE PAYLOAD = 2,858,390. THIS IS THE EQUIVALENT PAYLOAD DELIVERED BY ONE VEHICLE OVER 90 DAYS. SINCE $40 \times 10^6 \text{ KG}$ IS REQUIRED, THEN DIVIDE BY THE EQUIVALENT PAYLOAD TO GIVE A FLEET SIZE OF 14 VEHICLES.

RESULTS

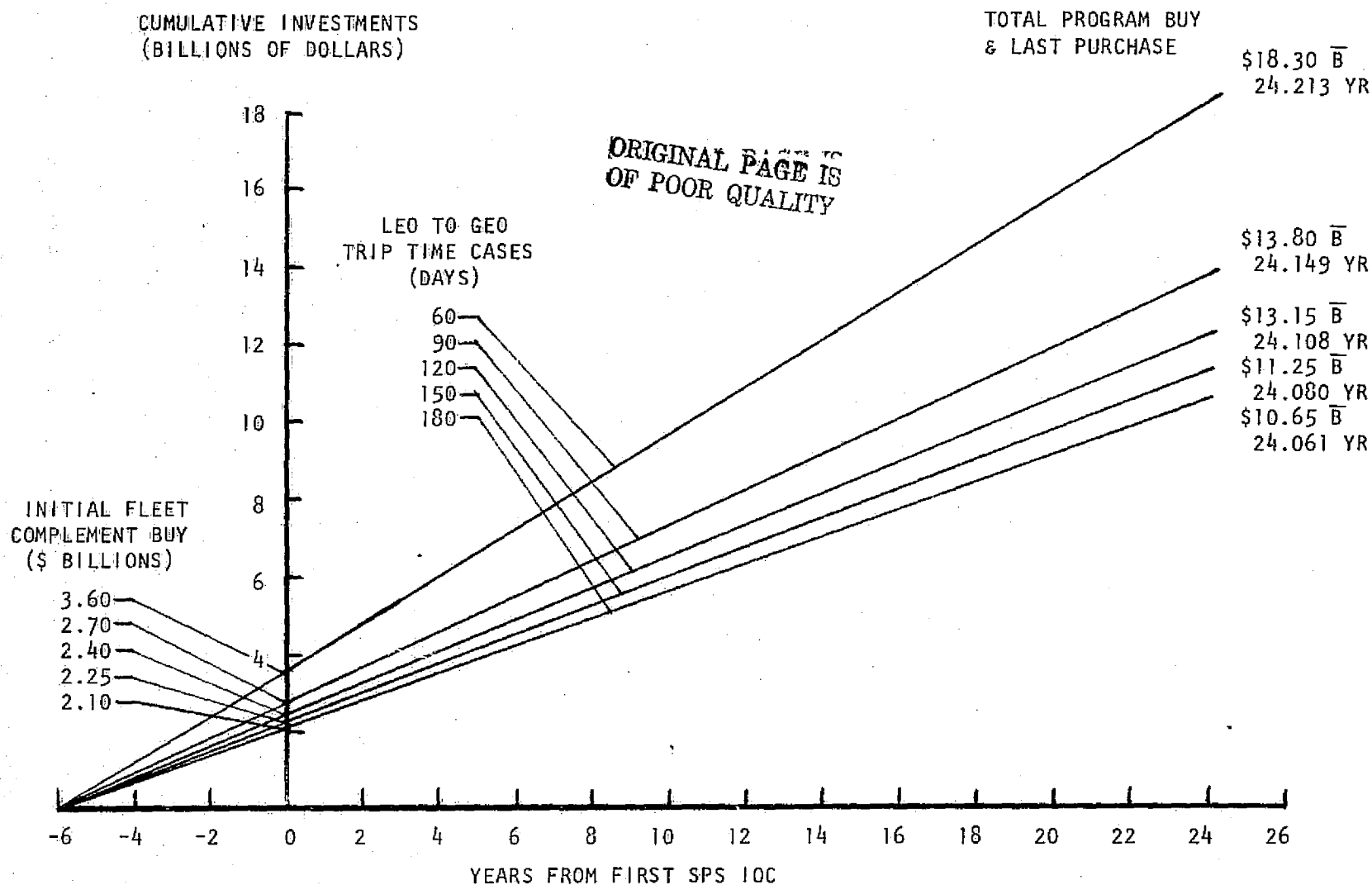
		ELECTRIC COTV LEO-TO-GEO TRIP TIMES					
		30 DAYS	60 DAYS	90 DAYS	120 DAYS	150 DAYS	180 DAYS
FLEET SIZES	CALCULATION	79.412	23.462	17.902	15.793	14.692	14.017
	ROUNDED	80	24	18	16	15	14
PROGRAM BUY	CALCULATION	422.703	121.626	91.783	80.410	74.449	70.809
	ROUNDED	423	122	92	81	75	71



COTV CAPITAL INVESTMENT STREAMS

The investment streams for capital purchase of the COTV's is developed from consideration of average vehicle cost, fleet size, total program buy, and vehicle life. For this analysis it was assumed that the average vehicle cost - in place - would be $\$150 \times 10^6$ regardless of the total numbers purchased. The example shown is for a 5-year vehicle "life" and assumes that the initial fleet production investment was begun six years prior to the first SPS IOC date. All LEO-to-GEO trip-time cases are shown except the 30-day case which is now recognized as not cost-effective. If the last purchase of 10-year life point was plotted for the 60-day trip-time, it would appear at $\$9.15 \text{ B}$ on the ordinate and 18.728 years on the abscissa, but the initial fleet complement investment point would remain unchanged.

COTV CAPITAL INVESTMENT STREAMS



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TIME-VALUE OF MONEY IMPACT ON COST COMPARISONS

The time-value of money impact on cost comparisons is discussed in the figure and expressed for all trip-time cases in terms of \$/kg of COTV payload. The investment dollars were subtracted from the 180-day trip time case and only the Δ differences are tabulated.

TIME-VALUE OF MONEY IMPACT ON COST COMPARISONS

THE TIME-VALUE OF MONEY MUST BE CONSIDERED IN THE COST COMPARISONS OF THE ELECTRIC COTV ALTERNATIVES.

(1) SATELLITE CAPITAL INVESTMENT

LEO-TO-GEO TRANSFER TIMES SHOULD BE CONSIDERED AS PERIODS OF TIME DURING WHICH THE INTEREST ON A CAPITAL INVESTMENT (E.G., THE SATELLITE VALUED AT APPROXIMATELY \$5 BILLION) IS LOST. FOR EXAMPLE, THE "INTEREST LOST" FOR A 180-DAY PERIOD AT A 7.5% DISCOUNT RATE IS APPROXIMATELY \$184.1 MILLION. APPORTIONED ON A SATELLITE MASS BASIS EQUATES TO \$4.603/KG.

(2) COTV CAPITAL INVESTMENT

FROM THE PREVIOUS CHART IT IS TO BE NOTED THAT THE SHORTER TRIP-TIME CASES NOT ONLY REQUIRE HIGHER INITIAL INVESTMENTS, BUT ALSO THE INVESTMENT STREAM IS HIGHER. AGAIN, USING A 7.5% DISCOUNT RATE, FUTURE VALUE COMPUTATIONS WERE MADE FOR EACH INVESTMENT STREAM AND THE DIFFERENCES IN \$/KG PAYLOAD (AGAINST THE LOWER COST CASE—E.G., THE 180-DAY TRIP-TIME CASE) WERE ESTABLISHED.

	LEO-TO-GEO TRIP TIMES					
	30 DAYS	60 DAYS	90 DAYS	120 DAYS	150 DAYS	180 DAYS
INTEREST LOST (\$/KG)	0.755	1.516	2.280	3.050	3.824	4.603
COTV INVEST- MENT Δ 's (\$/KG)	40.128	5.877	2.403	1.158	0.492	-

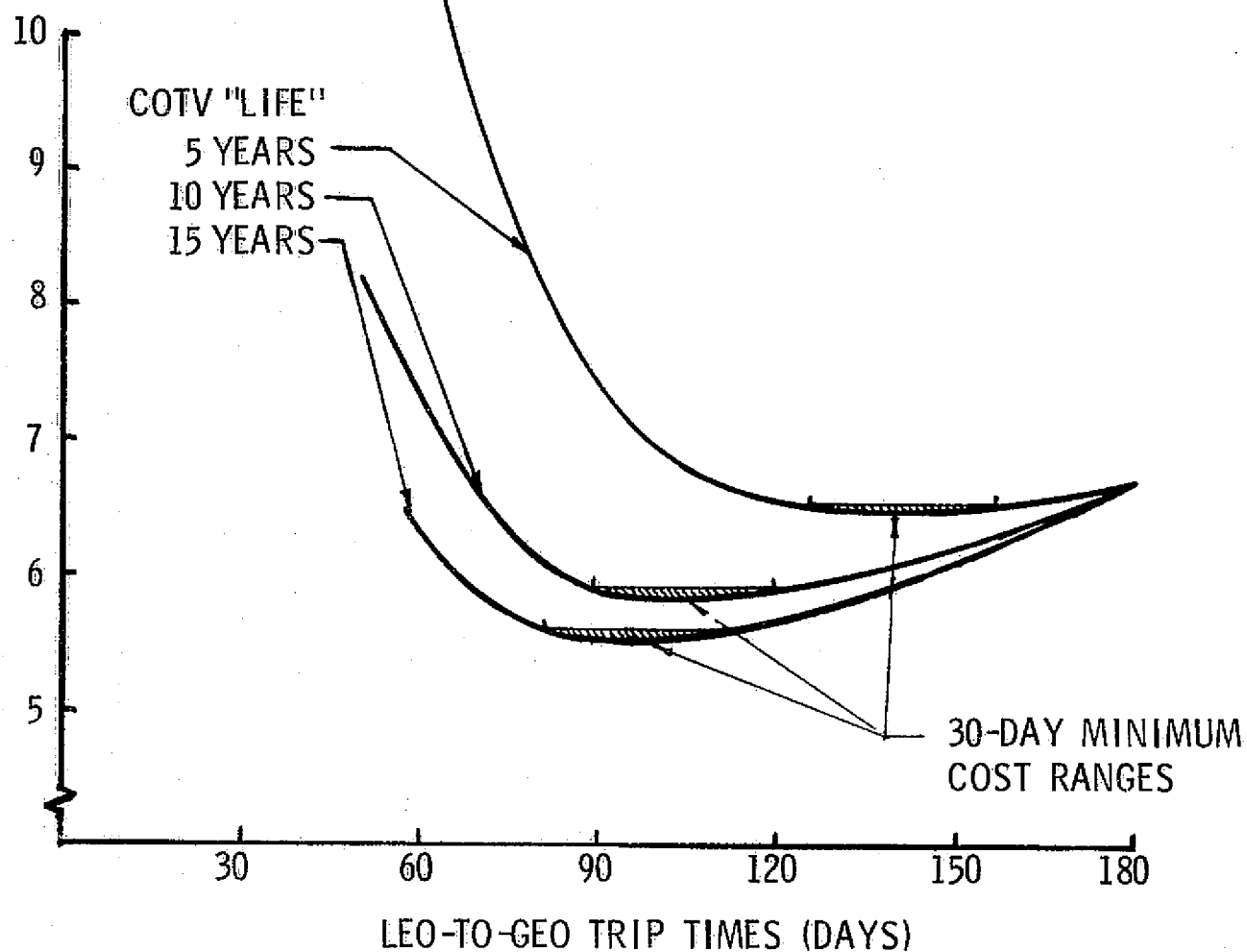


ELECTRIC COTV COST COMPARISONS

Cost in terms of \$/kg of COTV payload for resupply, operations, "lost" interest, and investment Δ 's were summed and plotted for each of the LEO-to-GEO trip time cases. The results are presented for COTV lifetimes of 5, 10 and 15 years illustrating the shift in minimum cost ranges toward the shorter LEO-to-GEO trip-times. These results are encouraging from the standpoint of long-duration transfer palatability. Within reasonable bound and for the performance values and cost assumptions presented, the physical size of the electric CTOV vehicle can be changed without appreciably altering these results.

ELECTRIC COTV COST COMPARISONS

COMPARATIVE COSTS
(\$/KG PAYLOAD)



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SATELLITE CONSTRUCTABILITY



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OBJECTIVES

- EVALUATE CONSTRUCTABILITY OF SATELLITE AND SUPPORTING ORBITAL BASES
 - PRECURSOR AND CONSTRUCTION OPERATIONS SCENARIOS
 - CONSTRUCTION/INSTALLATION PROCEDURES
 - EQUIPMENT
 - SUPPORT SYSTEMS
 - MASS DELIVERIES
 - MAN'S ROLE
 - TIME LINES AND CREW SIZES
- IDENTIFY MAJOR PROBLEM AREAS



STATUS
TASK 2.2 SATELLITE CONSTRUCTABILITY

SUBTASKS

MAJOR OUTPUTS

2.2.1 SATELLITE CONSTRUCTION
CONCEPT AND
CONSTRUCTION
PROCESSES

- CONSTRUCTION OPERATIONS
- CONSTRUCTION SCHEDULE
- CONSTRUCTION CREW SIZE REQUIREMENTS
- SATELLITE CONSTRUCTION BASE (SCB) CONCEPT

2.2.2 MAINTENANCE

- ANNUAL SPARES REQUIREMENTS
- MAINTENANCE CONCEPTS
- OPERATIONS & MAINTENANCE CREW SIZE REQUIREMENTS

2.2.3 LOGISTICS

- CONSTRUCTION & MAINTENANCE MASS FLOW DEMANDS
- PAYLOAD PACKAGING MIXES
- SPACE LOGISTICS TRAFFIC MODEL

2.2.4 SUPPORT SYSTEMS
REQUIREMENTS

- CONSTRUCTION SUPPORT EQUIPMENT CONCEPTS
- SPACE CONSTRUCTION BASE LOGISTICS SUPPORT
- CREW WORK STATIONS & HABITATS
- MAINTENANCE SUPPORT EQUIPMENTS
- OPERATIONS & MAINTENANCE BASE CONCEPT

2.2.5 PERSONNEL REQUIREMENTS

- ORBITAL PERSONNEL COMPLEMENTS
- GROUND SUPPORT (LAUNCH SITE) PERSONNEL
- PERSONNEL UTILIZATION CONCEPTS

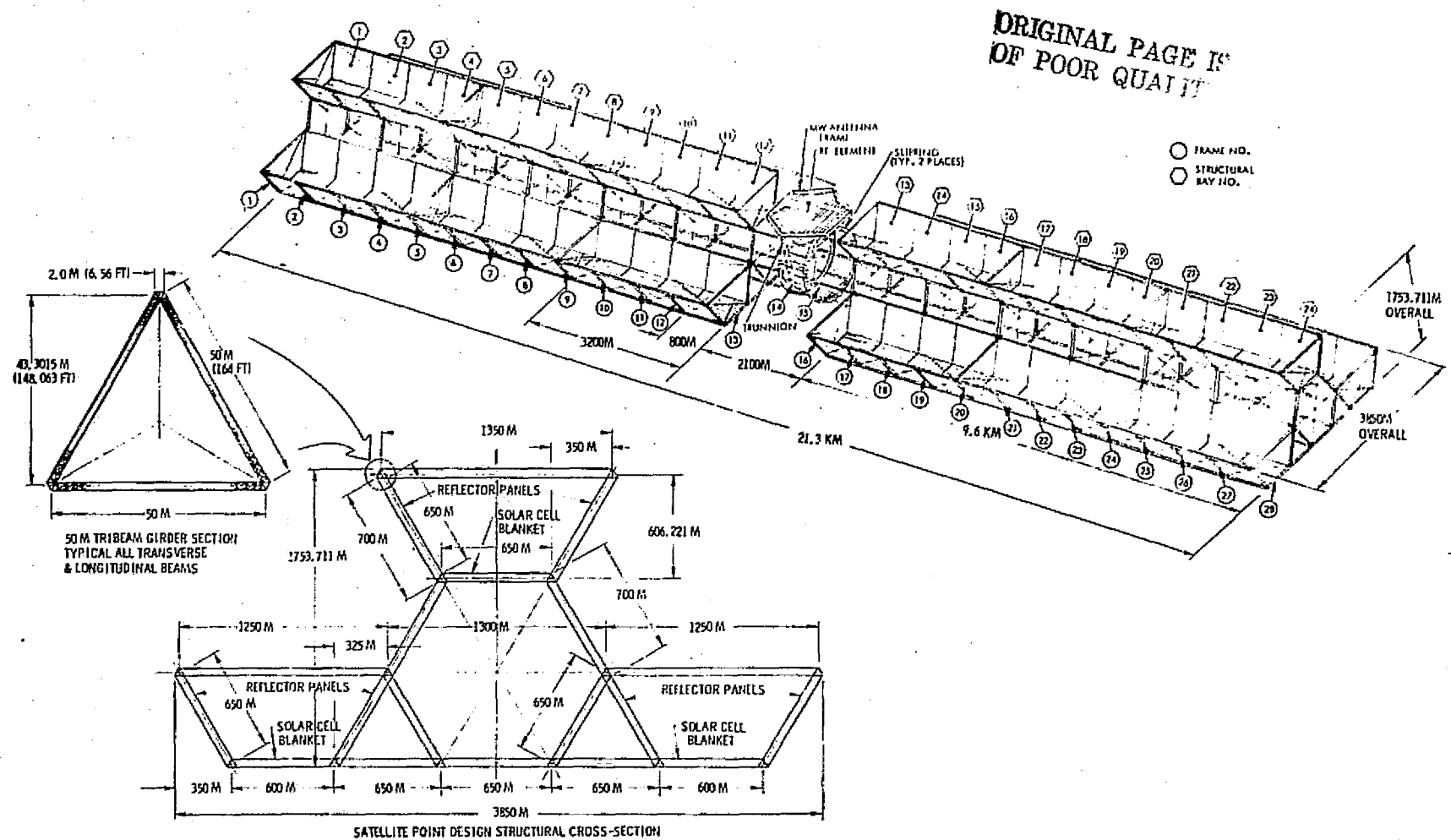


SATELLITE DESCRIPTION

The satellite is comprised of two wings and a center section upon which the slip ring and antenna is mounted. Each wing consists of 12 bays 800 m long, numbered as shown on the isometric representation of the satellite. Referring to the cross section view, solar blanket strips 750 m long and 25 m wide are installed along the bottom of the three troughs as indicated, while the reflector panels are installed in the trough sides.

The satellite structure is constructed from 50 m tribeams which are fabricated from the basic building block of 2 m tribeams as shown in the tri-beam cross section. The overall construction concept entails use of a satellite construction base, described in a later chart, to construct one wing, commencing with bay 1, complete the center section, and then fabricate the second wing, commencing with Bay 24. Installation of the power generating equipment is accomplished concurrently with fabrication of each bay.

SATELLITE DESCRIPTION



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SATELLITE MASS SUMMARY

(KG X 10⁻⁶)

PRIMARY STRUCTURE	2.32	● MW SYSTEM	(8.663)
SOLAR COLLECTOR/CONV.	10.97	KLYSTRONS	4.320
SOLAR BLANKETS	(8.50)	WAVEGUIDES	2.560
REFLECTORS	(1.34)	KLYSTRON THER. CONT	1.408
POWER DIST. & CONT.	(0.96)	SENSING & CONTROL	0.375
ACS	(0.12)	● PWR DIST. & CONT.	(3.469)
IMS	(0.05)	● IMS	(0.360)
ANTENNA SECTION	14.243		
● NON-ROT. STRUCTURE	(0.442)		
INNER RINGS/CROSS TIES	0.040		
SLIP RINGS	0.208		
ROT. DR. MOTOR & MECH.	0.191		
● ROTATING STRUCTURE	(1.042)		
OUTER RINGS/TRUNIONS	0.078		
EQUIP SUPPORT	0.888		
ANTENNA FRAME, WEB, & TENSIONING MECH.	0.076		

TOTAL MASS	27.533 X 10 ⁶ KG
WITH 30% GROWTH	35.793 X 10 ⁶ KG



SATELLITE CONSTRUCTION GUIDELINES

- SINGLE INTEGRATED SCB
- CONTINUOUS STRUCTURE FABRICATION
- SOLAR CONVERTER INSTALLATION SIMULTANEOUS WITH STRUCTURAL FAB
- ANTENNA CONSTRUCTED CONCURRENTLY WITH FIRST WING AND POSITIONED AS A UNIT
- NO SCHEDULED EVA
- 90 DAY CONSTRUCTION SCHEDULE



SATELLITE CONSTRUCTION SCHEDULE

A single integrated construction facility builds the structure, installs the solar blankets, the reflectors, the power distribution system and other subsystem elements located in the wings. Construction starts with one wing tip and progresses toward the center section where the rotating joint for the MW antenna is to be located, and hence continues outboard building wing No. 2 and terminating at the wing tip.

The first eight days are designated for preparation of the construction facility, including distribution and installation into dispensers of material (e.g., structure cassettes, solar blankets, etc.) required to commence construction. During this time satellite materials are arriving from LEO daily with delivery scheduled for completion by the 60th day.

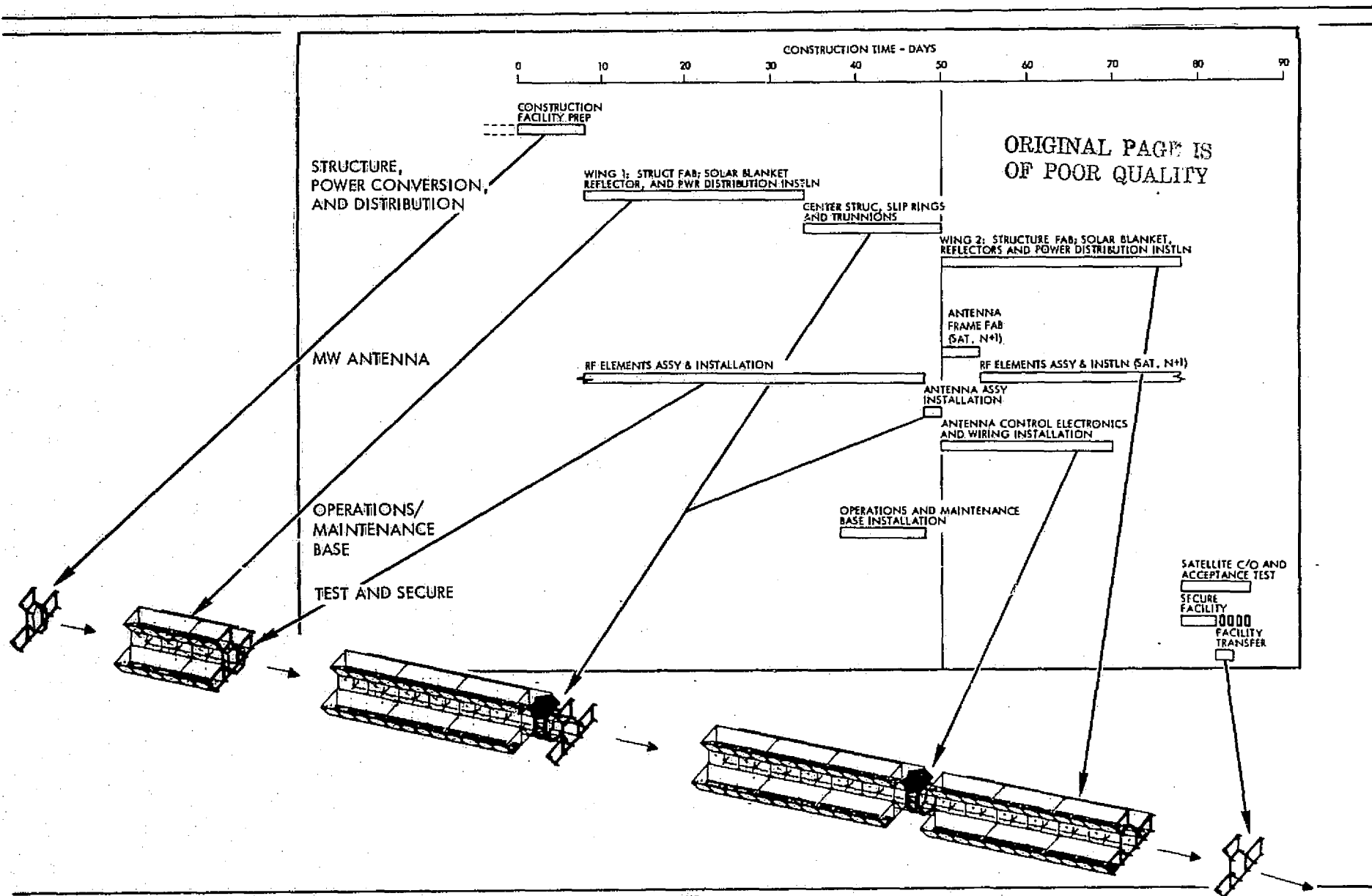
Each satellite wing consists of 12 bays 800-m long. These are constructed at the rate of one every two days using three 8-hour shifts per day. The structure and installation of the power conversion system of wing No. 1 is completed on the 34th day. While the wing No. 1 construction is taking place the MW antenna crews are proceeding with the assembly, test, and installation of the antenna elements into the antenna frame. The antenna assembly continues during the construction of the center section.

Subsequent to completion of wing No. 1 the construction facility constructs the longerons and frames in the center section, installs the slip rings, constructs the tension supports, installs the trunions, and installs power wiring in the center. Although 16 days are scheduled for this activity, the timeline requires only 12 days with two additional days scheduled for transfer of the antenna to the trunion mounts. Two days are allowed for contingencies.

Immediately upon completion of the center section primary structure the facilities for the operation and maintenance are installed and the first operational maintenance crew arrives to support installation of the antenna control electronics and satellite checkout, which takes place from day 50 through day 69.

Final satellite checkout and acceptance testing is completed on day 86. Use of the construction facility is completed on day 78 and flyaway transfer to the construction site of the next satellite occurs on day 84.

NTH SATELLITE CONSTRUCTION SEQUENCE



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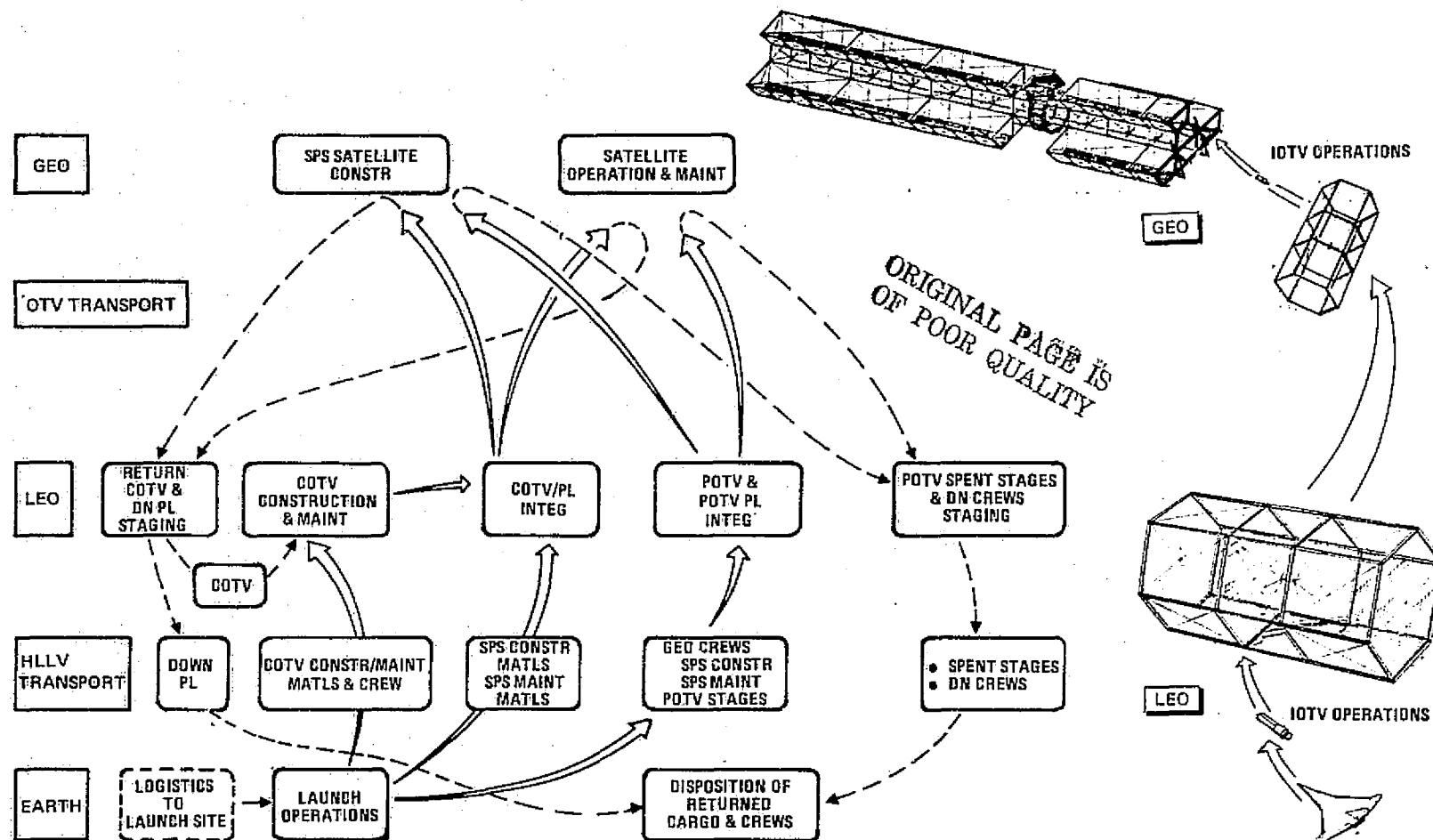
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SPACE OPERATIONS CONCEPT

Space operations entail the use of four types of transportation vehicles. The HLLV delivers cargo to LEO where it is transferred to the EOTV by IOTV's. The EOTV transits to GEO by means of electric propulsion. Upon reaching GEO, the cargo is transferred to the Satellite Construction Base by IOTV's.

Personnel are transported to LEO by HLLV's. Each increment of 48 crewmen is carried in a POTV. The two chemical stages which comprise a part of the POTV are carried separately and mated in LEO for the transit to GEO and subsequent return. Spent stages are returned to earth as part of the "down" cargo.

SPACE OPERATIONS CONCEPTS



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SATELLITE CONSTRUCTION BASE (SCB)

Construction of the satellites takes place in GEO, each satellite being constructed at its designated longitudinal location. All construction activities are supported by a single integrated construction base which produces satellites at the rate of 4 per year (and later 5 per year) during the mature portion of the program. Upon completion of one satellite the base is moved to the operational location of the next satellite for construction of that satellite.

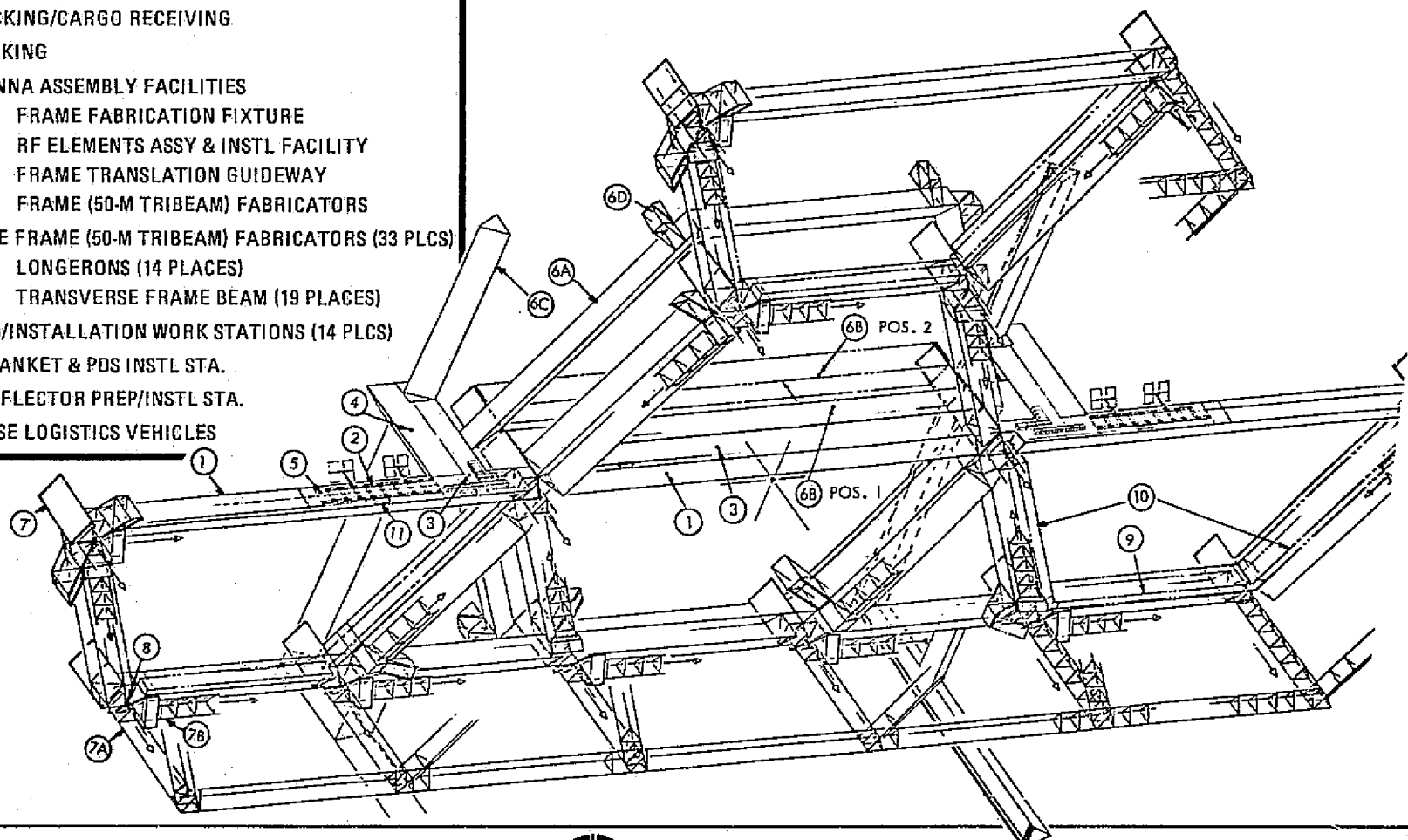
The construction base consists of the satellite construction fixture, the construction equipment, and the base support facilities and equipment. The construction fixture is a rugged heavy gage metal structure on which all elements of the construction base are mounted. The fixture constitutes the reference surfaces for the construction operations and the locating jig for the equipment which constructs/installs various elements of the satellite in situ.

The major construction equipment includes the 50 m tribeam fabricators; the deployment equipment for the solar cell blankets, the solar reflector panels, the power distribution conductors, the cables for retention of the solar blankets, and the structure tensioning cables; the assembly facility for the MW antenna mechanical modules; and the equipment for installation of the MW antenna elements into the antenna frame. The location of most of these elements is identified on the chart.

SATELLITE CONSTRUCTION BASE (SCB) (GEO LOCATED)

- ① CONSTRUCTION FIXTURE
- ② BASE SUPPORT FACILITIES & EQUIP (2 EA)
340-CREW MEMBER SUPPORT
BASE SUBSYSTEM, MAINTENANCE SHOPS
BASE MGMT, COMM., CONTROL, LOGISTICS
- ③ WAREHOUSE
- ④ EOTV DOCKING/CARGO RECEIVING
- ⑤ POTV DOCKING
- ⑥ MW ANTENNA ASSEMBLY FACILITIES
 - ⑥A FRAME FABRICATION FIXTURE
 - ⑥B RF ELEMENTS ASSY & INSTL FACILITY
 - ⑥C FRAME TRANSLATION GUIDEWAY
 - ⑥D FRAME (50-M TRIBEAM) FABRICATORS
- ⑦ SATELLITE FRAME (50-M TRIBEAM) FABRICATORS (33 PLCS)
 - ⑦A LONGERONS (14 PLACES)
 - ⑦B TRANSVERSE FRAME BEAM (19 PLACES)
- ⑧ BEAM FAB/INSTALLATION WORK STATIONS (14 PLCS)
- ⑨ SOLAR BLANKET & PDS INSTL STA.
- ⑩ SOLAR REFLECTOR PREP/INSTL STA.
- ⑪ INTRA-BASE LOGISTICS VEHICLES

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SCB MASS SUMMARY

BEAM MACHINES: 234 x 700 KG	163800 KG
TRIBEAM FABRICATORS: 39 x 2100 KG	81900
REFLECTOR INST. EQUIP: 6 x 20,000 KG	120000
SOLAR BLANKET DISPENSER: 73 x 2000 KG	146000
CABLE & CATENARY DISPENSER: 307 x 200 KG	61400
CABLE & CATENARY ATTACH. MACH: 79 x 500 KG	39500
	<u>612600</u>
MICROWAVE ANTENNA	450000
FABRICATION FIXTURE	2000000
BOOM MOUNTED MANIP. MODULES: 36 x 5000	
BEAM STATION LOG. VEHICLE: 6 x 5000	
CREW LOGISTICS VEHICLE 16 x 5000	
	<u>290000</u>
	3352600
HABITAT	2040000
BASE POWER SUPPLY	1000000
	<u>6392600 KG</u>
TOTAL	



MAJOR SATELLITE CONSTRUCTION ELEMENTS

STRUCTURE

{ 2 M BEAMS
50 M TRIBEAMS
INTEGRATED FRAMES & LONGERONS
ACS
CENTER STRUCTURE

SOLAR CONVERTER

{ BLANKETS
REFLECTORS
CONDUCTORS
DATA MGMT & CONTROLS

MW ANTENNA

{ RCR PANELS
KLYSTRONS
MECH MODULES
CONDUCTORS
DATA MGMT & CONTROLS



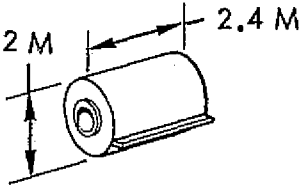
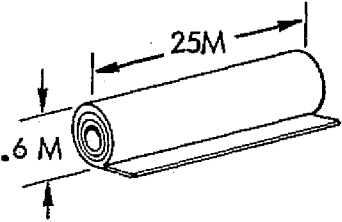
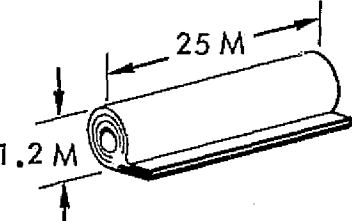
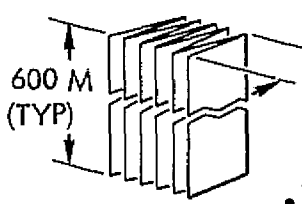
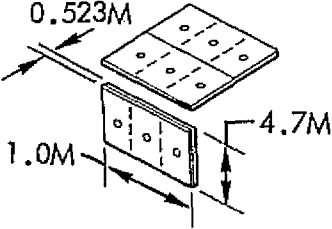
CARGO PACKAGING

These package configurations, sizes and specified quantities required for the construction of each satellite are designed for compatibility with the satellite construction concept and construction equipment. Three primary structure cassettes simultaneously feed each beam machine to produce the basic 2-meter triangular beam elements used in construction of the 50 meter girders. All cassettes contain sufficient length of material to complete one-half of the satellite structure, thus requiring replacement only once during satellite construction.

Each solar blanket roll is 750 M long - the length required for one bay. For a 600 M wide bay, 22 of these 25 M wide rolls are mounted side by side in the blanket layer and deployed simultaneously.

The reflector packaging and deployment is described in detail on a later chart, as are the MW antenna subarrays.

CARGO PACKAGING

SPS ELEMENT	PACKAGING	PACKAGE DIMENSIONS	NO. REQUIRED	NOTES
STRUCTURES	CASSETTES OF ALUMINUM TAPES		1188	6 DIFFERENT TAPE LENGTHS 2500 KG AVE MASS
SOLAR BLANKETS	ROLLS		1632	750 M LENGTH/ROLL 7136 KG/ROLL
REFLECTORS	ROLLS OF FABRIC-HINGED ALUMINIZED KAPTON SHEET		144	 • 32 "HINGED" PANELS • 12,780 KG/ROLL
MW ANTENNA WAVEGUIDE PANELS	SUB ARRAYS		6993	• ALL SUBARRAYS HAVE SAME OVERALL DIMENSIONS • 10 DIFFERENT POWER MODULE SIZES - QUANTITY VARIES WITH SIZE • SUBARRAY MASS (AVE) = 716 KG



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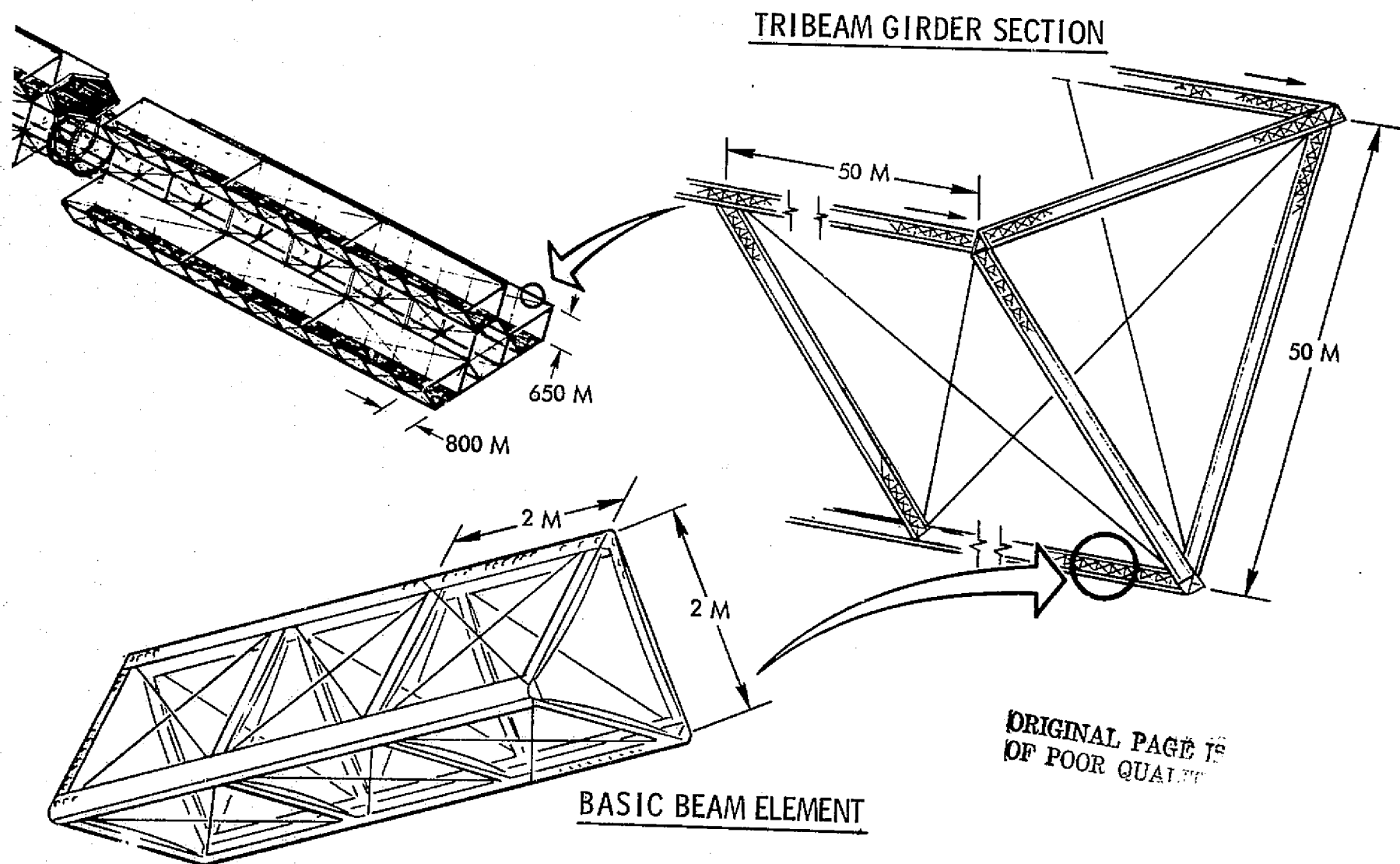
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PRIMARY STRUCTURE EVOLUTION

The two meter tribeam produced by the beam machine is the basic building block for the satellite structure. Its configuration is shown in the chart. The 50-m tribeam is the primary structural element of the satellite and is comprised of two meter tribeams as shown.

PRIMARY STRUCTURE EVOLUTION



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BEAM MACHINE

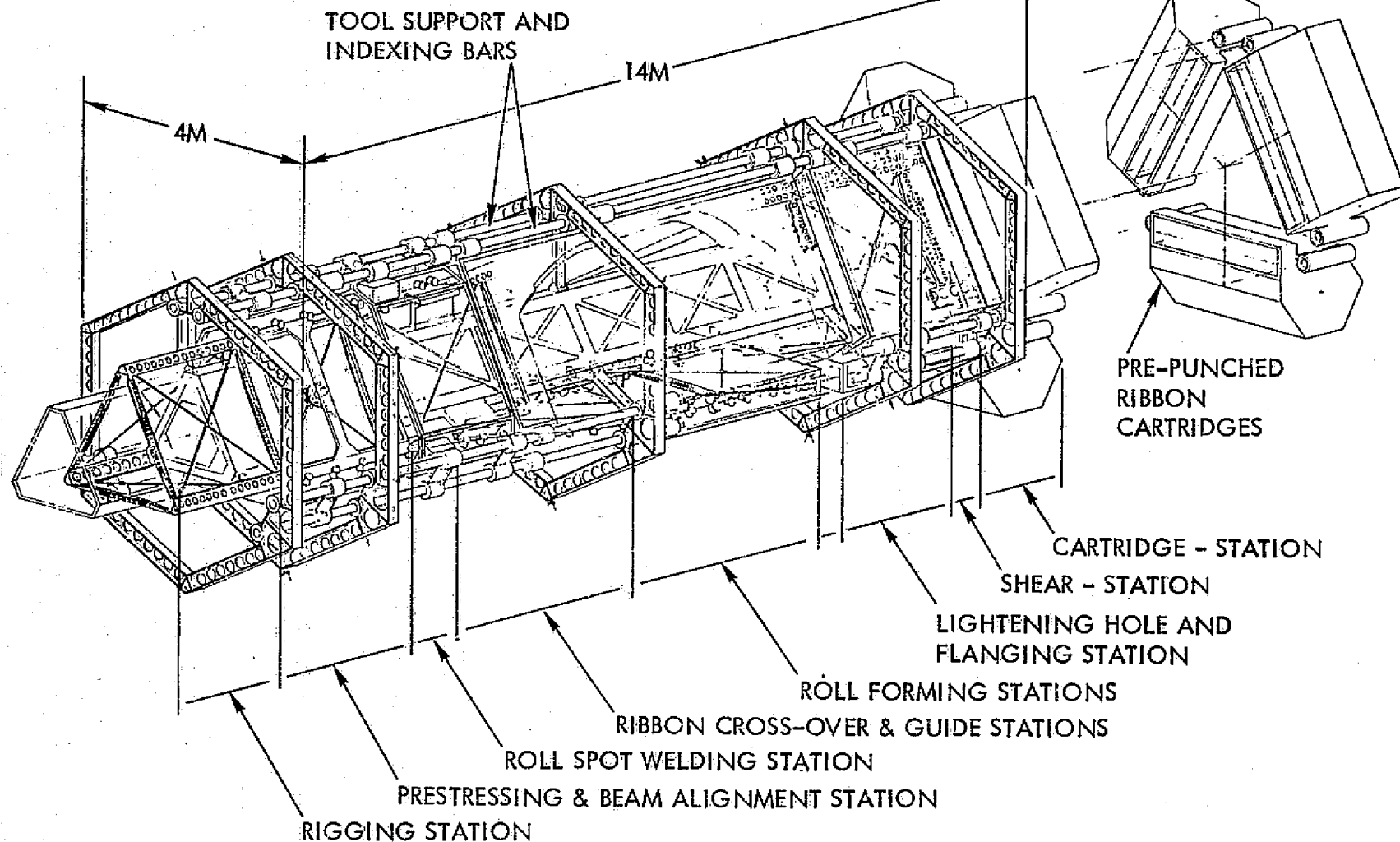
The structure configuration described is built up from 2-meter triangular shaped beams. Each beam is roll-formed in space from pre-punched, thin gage aluminum sheets. This figure is a cutaway view of the SPS structural element fabricator designed to provide an in-space, continuous fabrication of the triangular beam elements.

Prepunched material transported in cassettes to a structural fabrication facility (to be discussed) and then installed on the supply end of a beam machine. The material in each cassette is automatically threaded into and through the beam machine. Initially, the sheet material enters a shear station where the material rolls are longitudinally indexed. The material next passes into a hole-flanging and struct-forming station. On entry to this station, rolls turn up a small edge which, when passing through the beam fabricator, maintains a cross-load on the sheet when flanged and breake-formed to prevent loss of flat pattern width control. The material then progresses through longitudinal roll forms and is guided through the ribbon cross-over station into a roll seam welder used in a spaced spot-weld mode. The assembled sheet metal element next passes through the prestressing and alignment station where three sheet-metal shrinking-heads shorten and thicken the ribbon cross-braces. Tension-sensing elements control the operation on the basis of preload and alignment requirements fed into the machine from a central computer. The finished triangular shape exits the beam fabricator via a truss-rigging station. Here cable connections, quick-connects, and fittings are installed, when required, that permit the next higher level of assembly by automatic means. Six beam machines are required to produce one 50-meter triangular truss.

BEAM MACHINE

- ALL TOOL STATION MACHINES INDIVIDUALLY REPLACEABLE

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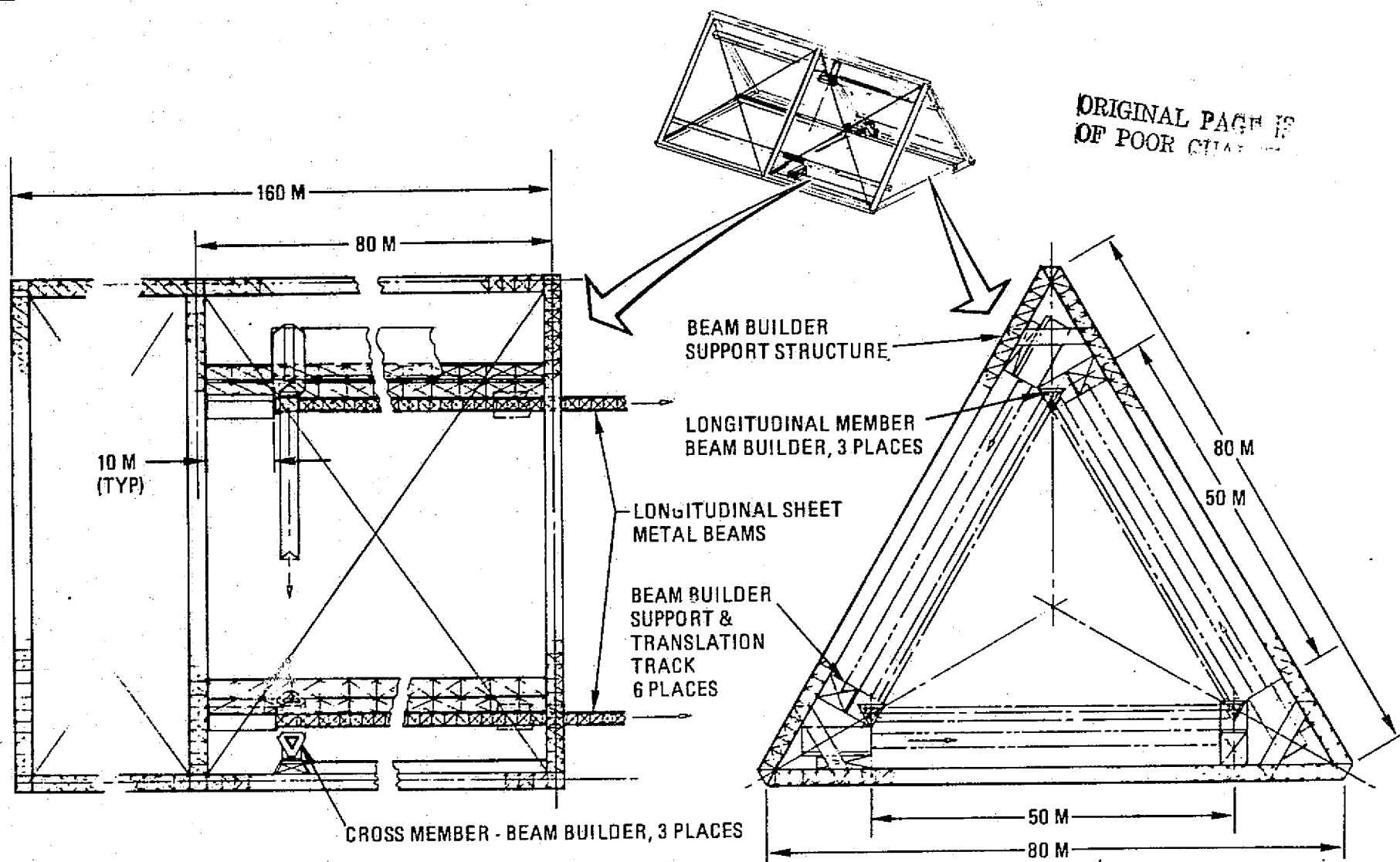
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TRI-BEAM COMPLEX

A housing concept for containment of the six beam machines required to fabricate a 50-meter tri-beam is shown. The structure of the tri-beam complex would be constructed by beam machines using a more substantial metal thickness, e.g., ~60 mil material, and could be fully enclosed. Two tri-beam complex lengths are indicated on the left side of the figure. The 160-meter length would be employed for the longitudinal tri-beam builders. The added length is used for machine "travel" in the event of malfunction, and an operating rate of 2 meters per minute would allow up to 40-minutes for machine repair before committing to an unscheduled facility shut down. Since the satellite structural cross-frames are attached to the longitudinals only during scheduled shutdown periods, they need not be designed for "travel" margins.

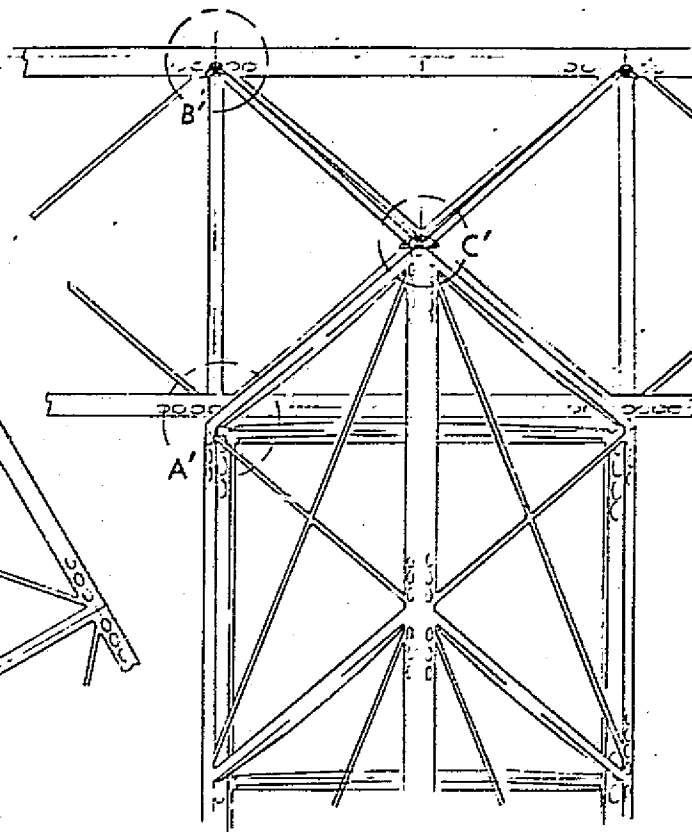
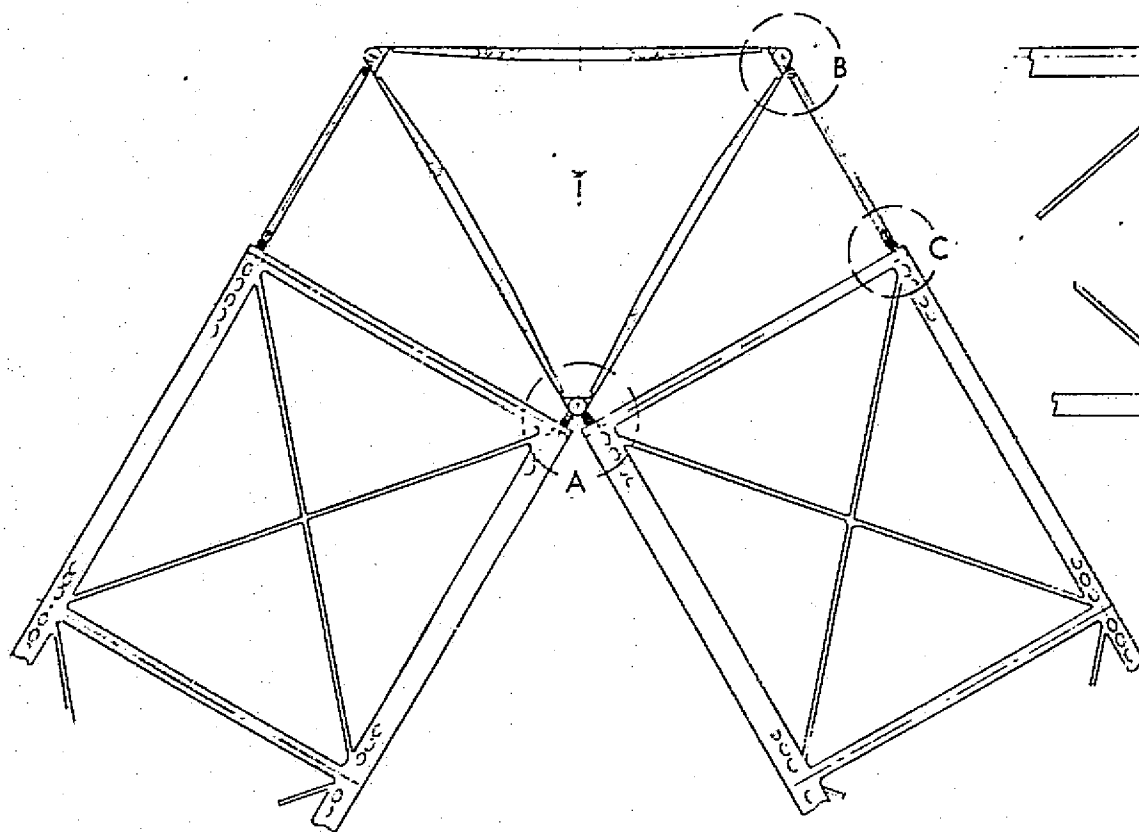
TRI-BEAM COMPLEX



TRIBEAM FABRICATION CONCEPT

The following three charts show concepts for beam joints designed to facilitate alignment and attachment.

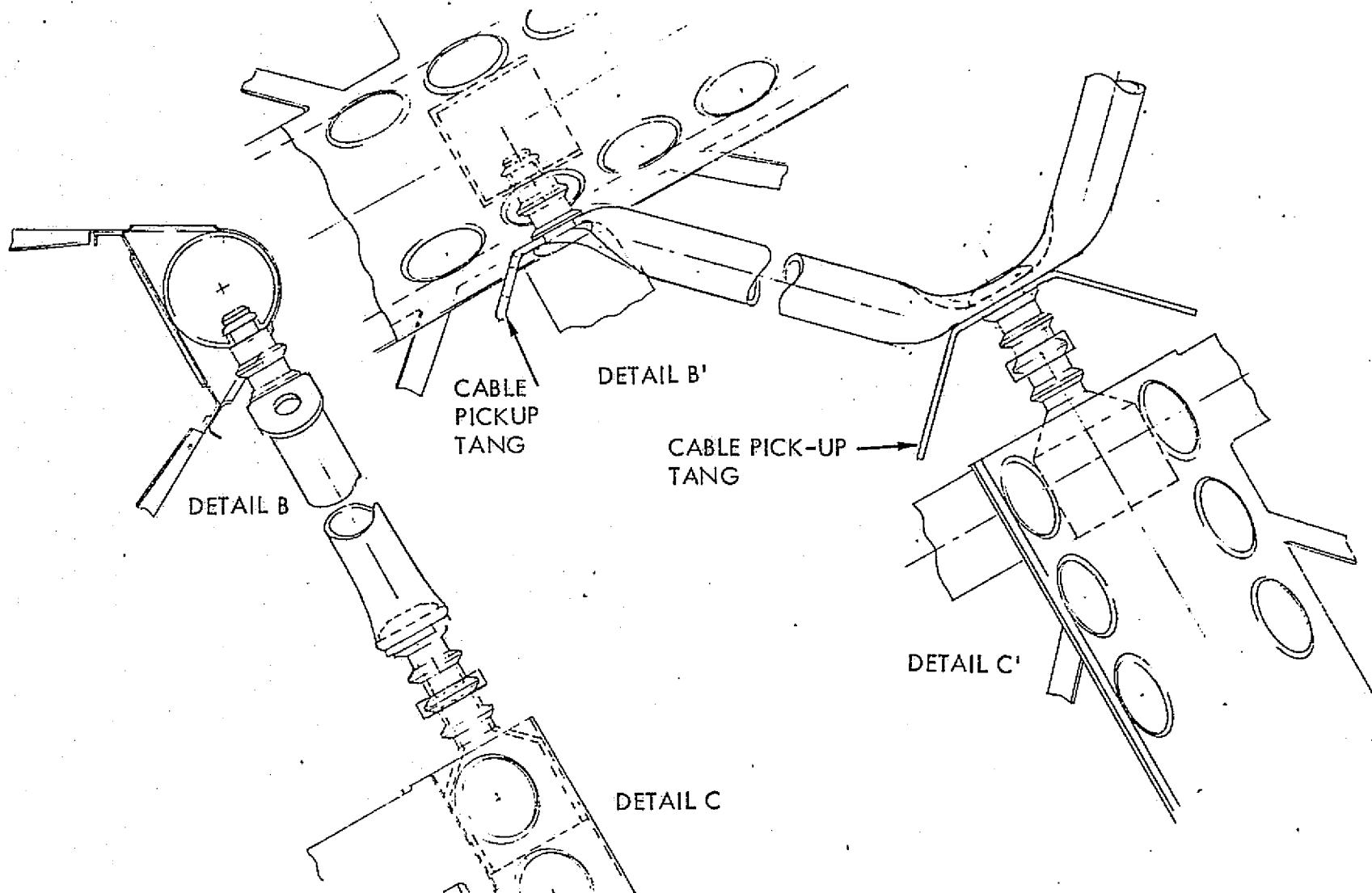
REFERENCE CONFIGURATION ATTACH FITTINGS CONCEPT 1



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REFERENCE CONFIGURATION



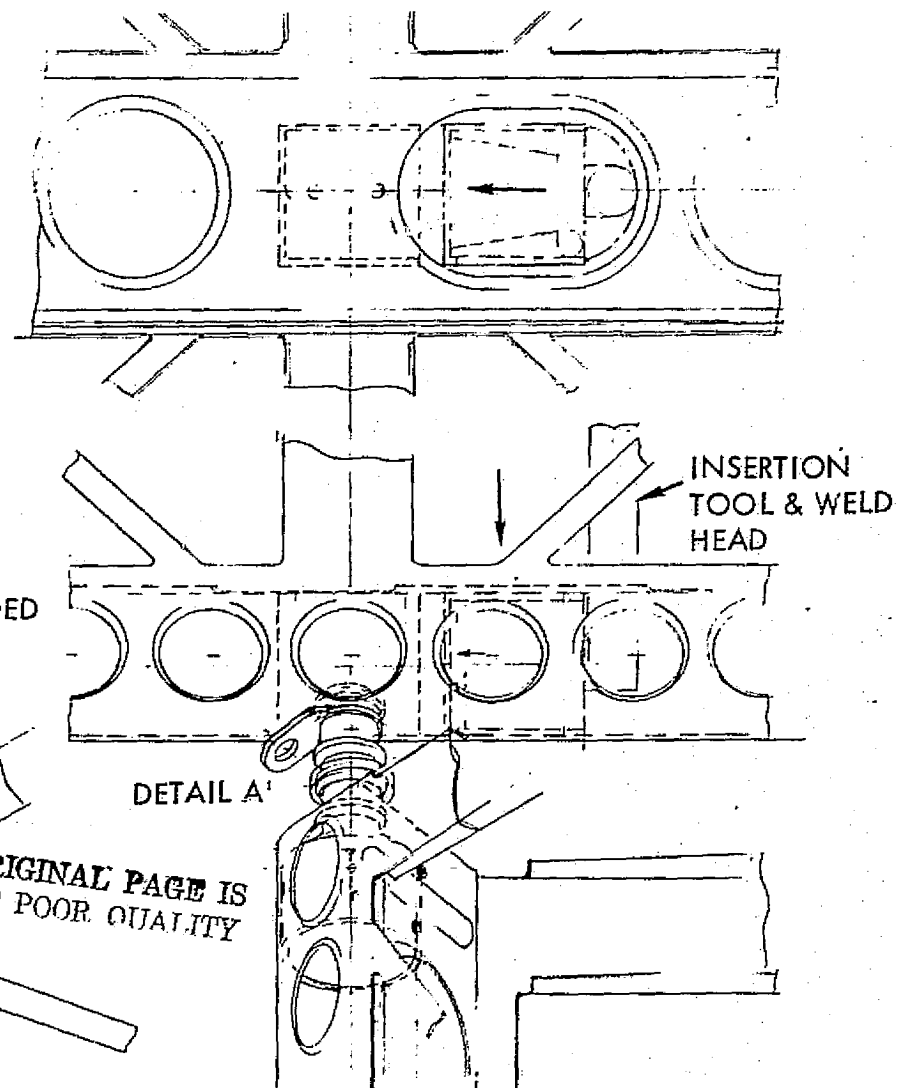
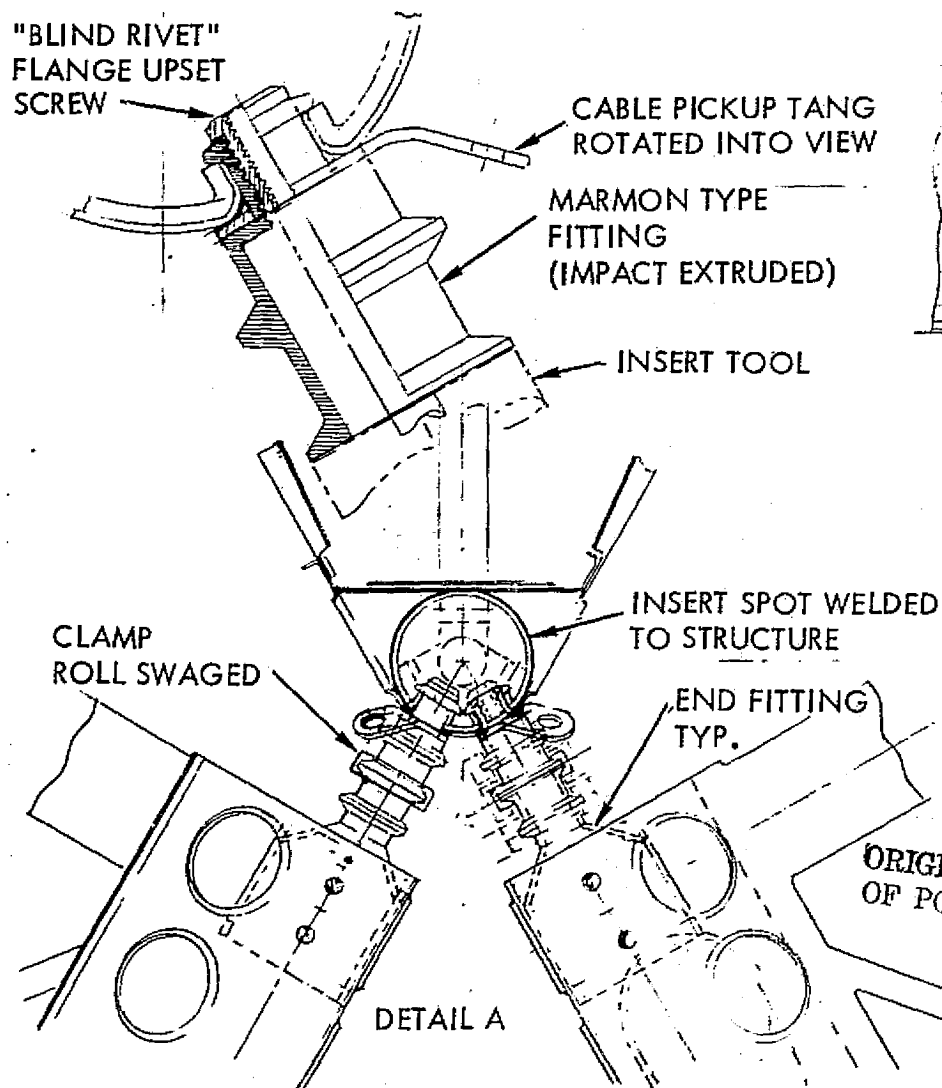
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REFERENCE CONFIGURATION DETAIL A & A'



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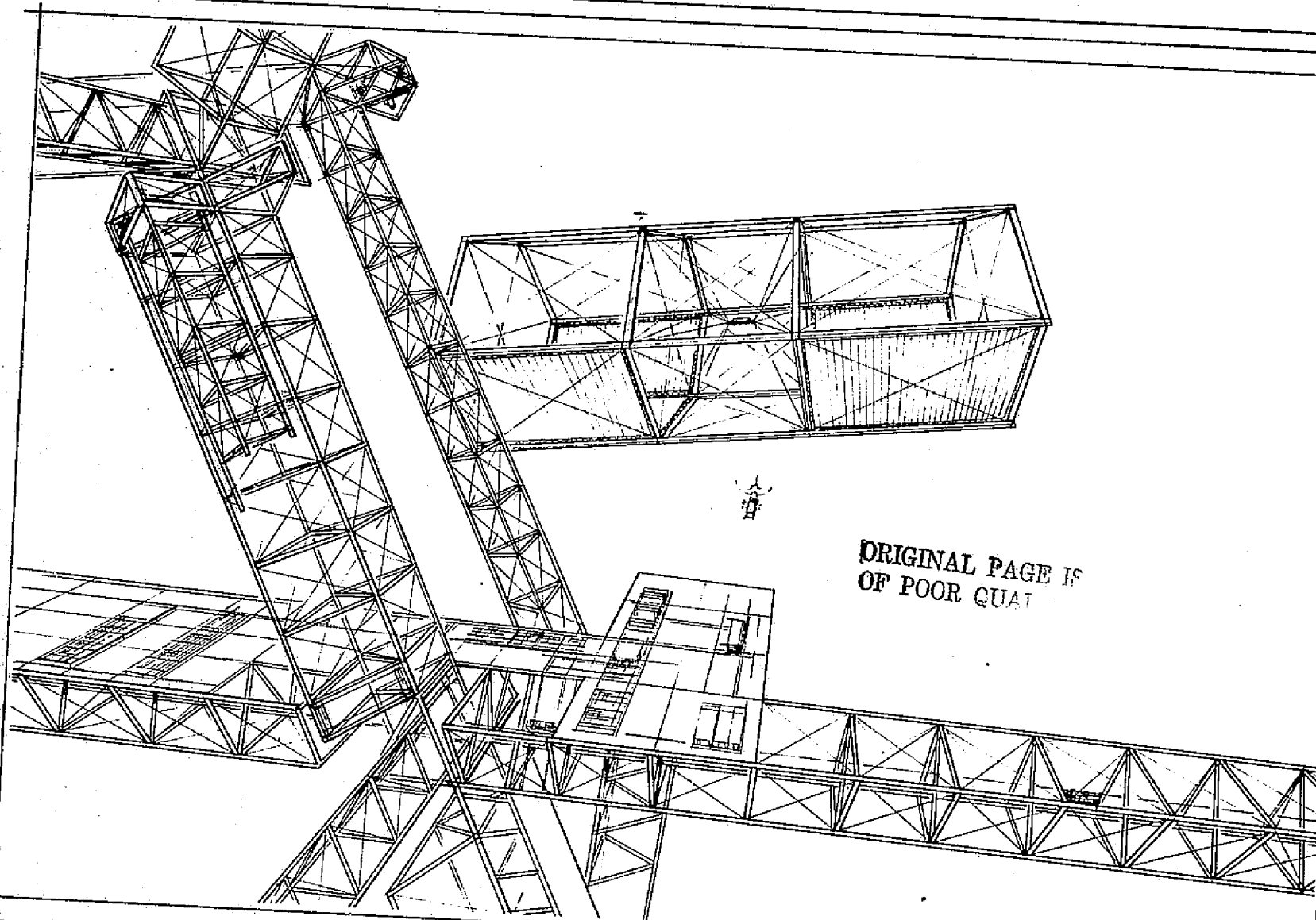
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GEO CARGO TRANSFER OPERATIONS



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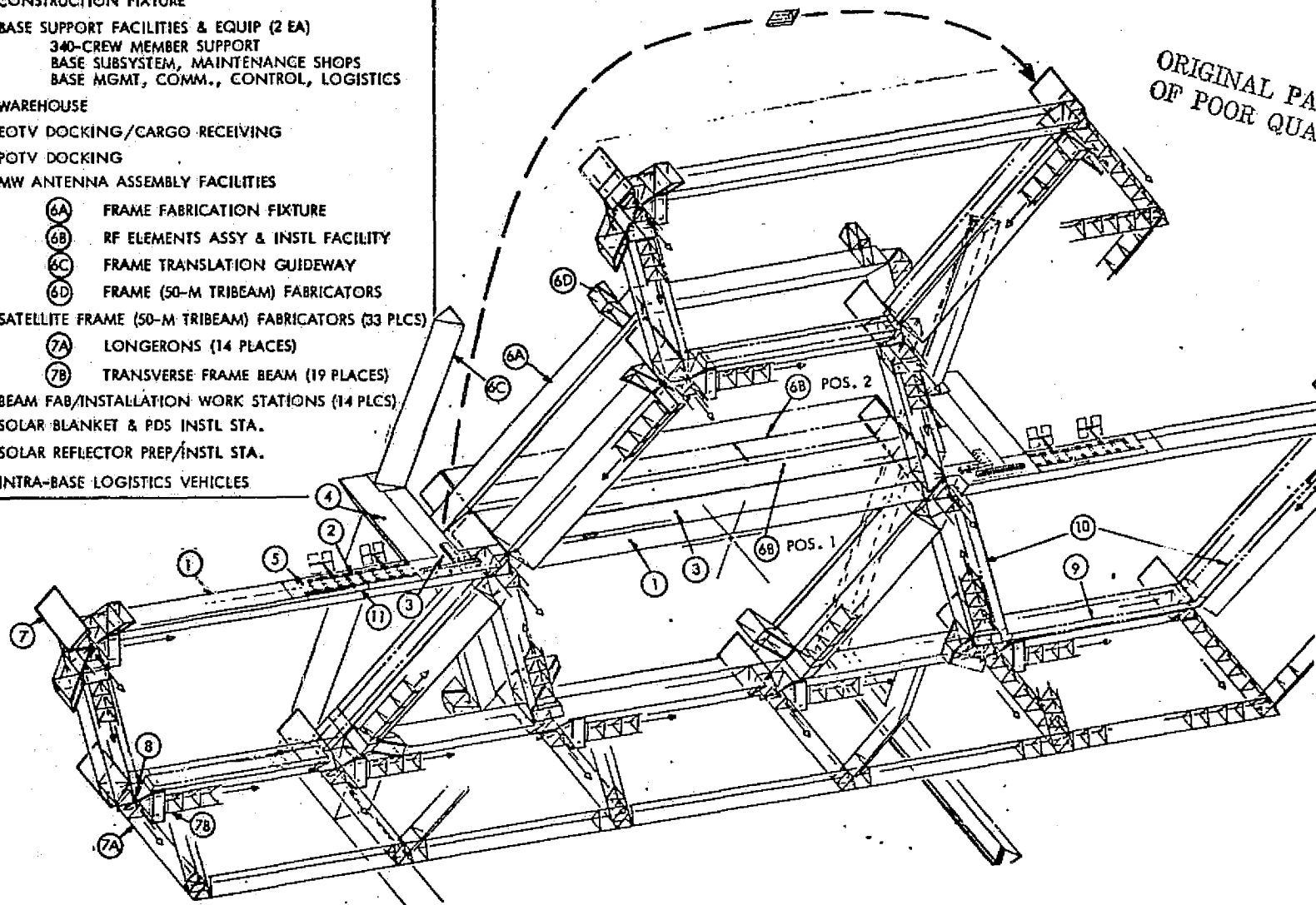
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SATELLITE CONSTRUCTION BASE (SCB)

Aluminum cassetts are delivered by free flying manned logistics vehicles (LV) to the various tribeam fabricating complexes. This chart shows a typical flight path of an LV from the warehouse area to a tribeam fabricator.

SATELLITE CONSTRUCTION BASE (SCB) (GEO Located)

- ① CONSTRUCTION FIXTURE
- ② BASE SUPPORT FACILITIES & EQUIP (2 EA)
340-CREW MEMBER SUPPORT
BASE SUBSYSTEM, MAINTENANCE SHOPS
BASE MGMT, COMM., CONTROL, LOGISTICS
- ③ WAREHOUSE
- ④ EOTV DOCKING/CARGO RECEIVING
- ⑤ POTV DOCKING
- ⑥ MW ANTENNA ASSEMBLY FACILITIES
 - ⑥A FRAME FABRICATION FIXTURE
 - ⑥B RF ELEMENTS ASSY & INSTL FACILITY
 - ⑥C FRAME TRANSLATION GUIDEWAY
 - ⑥D FRAME (50-M TRIBEAM) FABRICATORS
- ⑦ SATELLITE FRAME (50-M TRIBEAM) FABRICATORS (33 PLCS)
 - ⑦A LONGERONS (14 PLACES)
 - ⑦B TRANSVERSE FRAME BEAM (19 PLACES)
- ⑧ BEAM FAB/INSTALLATION WORK STATIONS (14 PLCS)
- ⑨ SOLAR BLANKET & PDS INSTL STA.
- ⑩ SOLAR REFLECTOR PREP/INSTL STA.
- ⑪ INTRA-BASE LOGISTICS VEHICLES



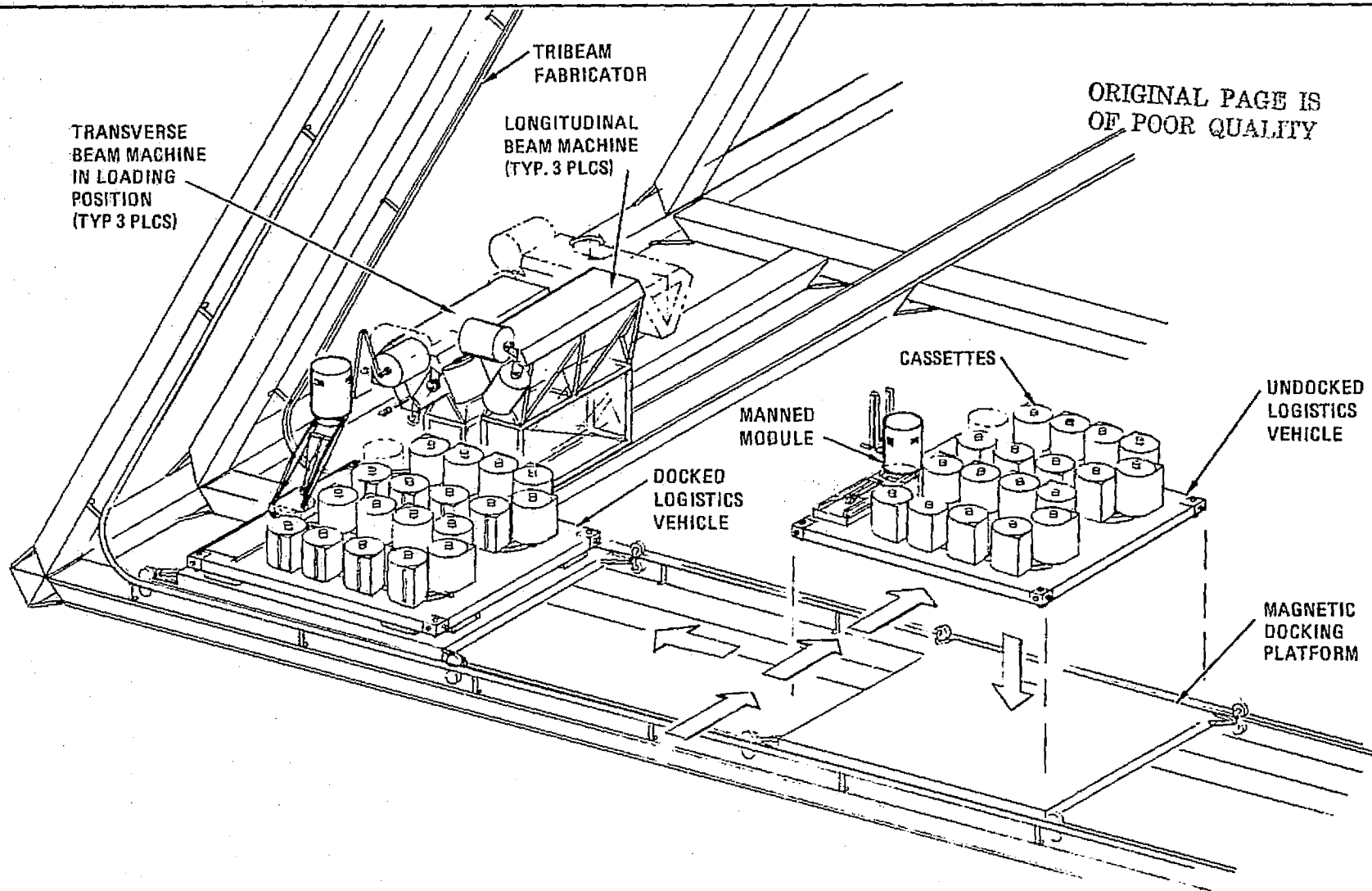
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FREE FLYING LOGISTICS VEHICLE (LV)

This perspective shows the LV in both the undocked and docked position. In the docked view, the manned module is in the process of removing an empty cassette for stowage on the platform prior to replacing it with a full cassette. The cassette is being removed from a transverse beam machine which has been rotated and translated into servicing position. The tracks to which the docking platform is attached are designed to permit travel to all three corners of the tribeam fabricator.

FREE FLYING LOGISTICS VEHICLE (LV)

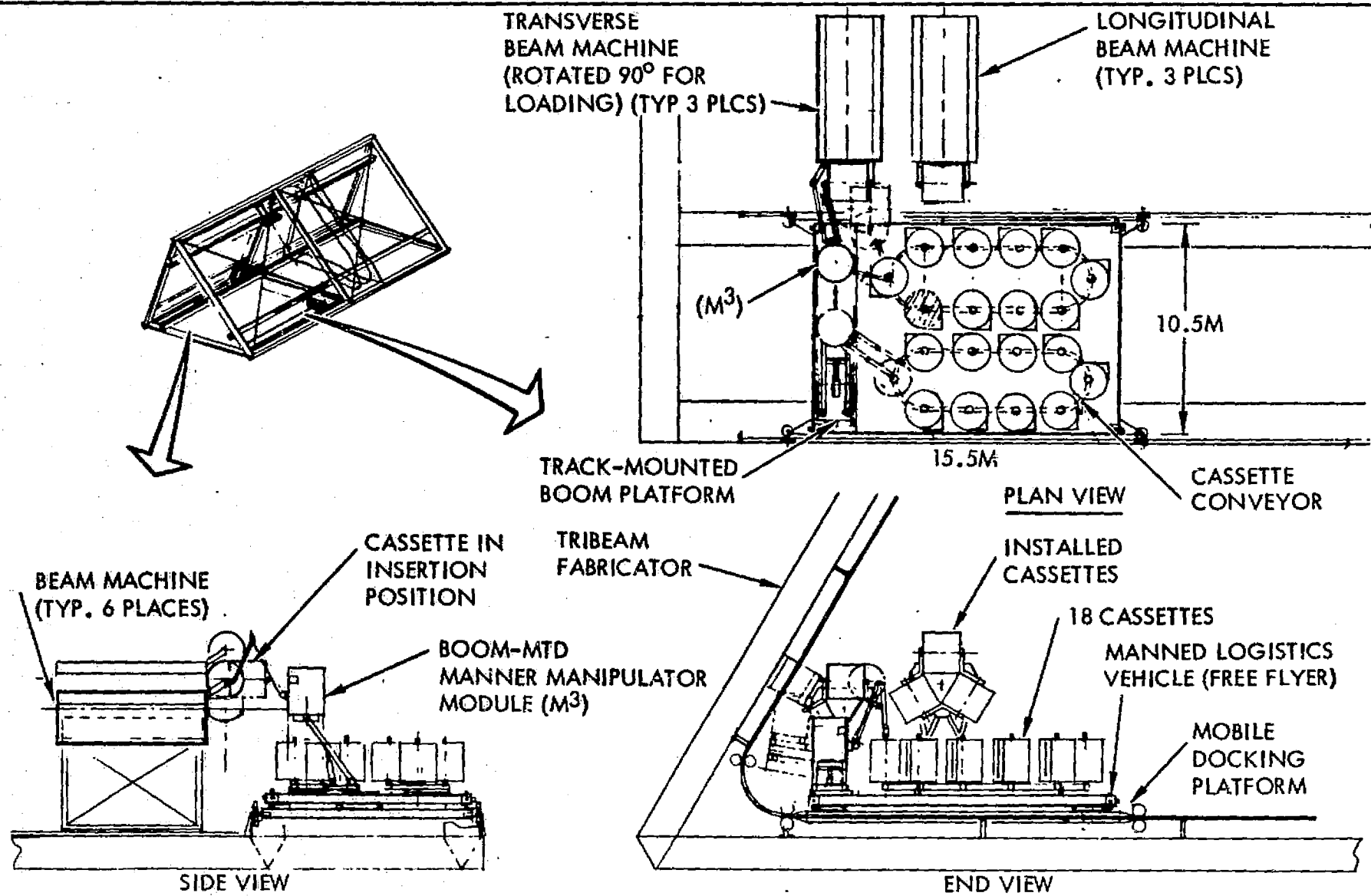


TRIBEAM FABRICATOR PREPARATION SERVICING CONCEPT

There are 33 tribeam fabricators utilized for satellite construction. These fabricators are installed in 14 general locations. Each fabricator must be loaded with 18 aluminum cassettes (3 per each of 6 beam machines) twice to support construction of one satellite, since the cassettes are sized to provide material for one wing only. The cassettes are transported from the warehouse area of the SCB to the various locations. This can be done either by a vehicle traveling on tracks or cables, or by a free flier. The network of tracks (or cables) which would be required for servicing the various locations from the warehouse area is complex and involves numerous changes of direction, some of which would be difficult to traverse. For these reasons, the free flying mode was selected. The concept consists of a chemically propelled and stabilized manned logistics vehicle (LV) capable of transporting 18 cassettes. The cassettes are attached to a conveyor on a detachable flatbed, which permits preparation of one load while the other is being delivered. The loaded LV docks on a track-mounted magnetic docking pad located at the rear of the fabricator. The tracks traverse the three sides of the fabricator, thus providing access by the LV to the six beam machines. Each empty cassette, mounted in a swivel hub and secured at the other end by a yoke arrangement, is removed and replaced by a full cassette. It is noted that the beam machines which construct the cross beams rotate and translate into position parallel to the longitudinal machines to facilitate unloading and loading.

The initial loading operation is conducted during preparation of the SCB for the next satellite construction. The second operation is conducted following completion of the first wing. Sufficient LV's are available to permit accomplishment of the 8 hour operation at the various stations within the overall construction time line. LV propellant requirements are minimal, amounting to approximately 850 kg per sortie.

TRIBEAM FABRICATOR SERVICING CONCEPT



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TRIBEAM FABRICATOR (TBF) SERVICING TIMELINE

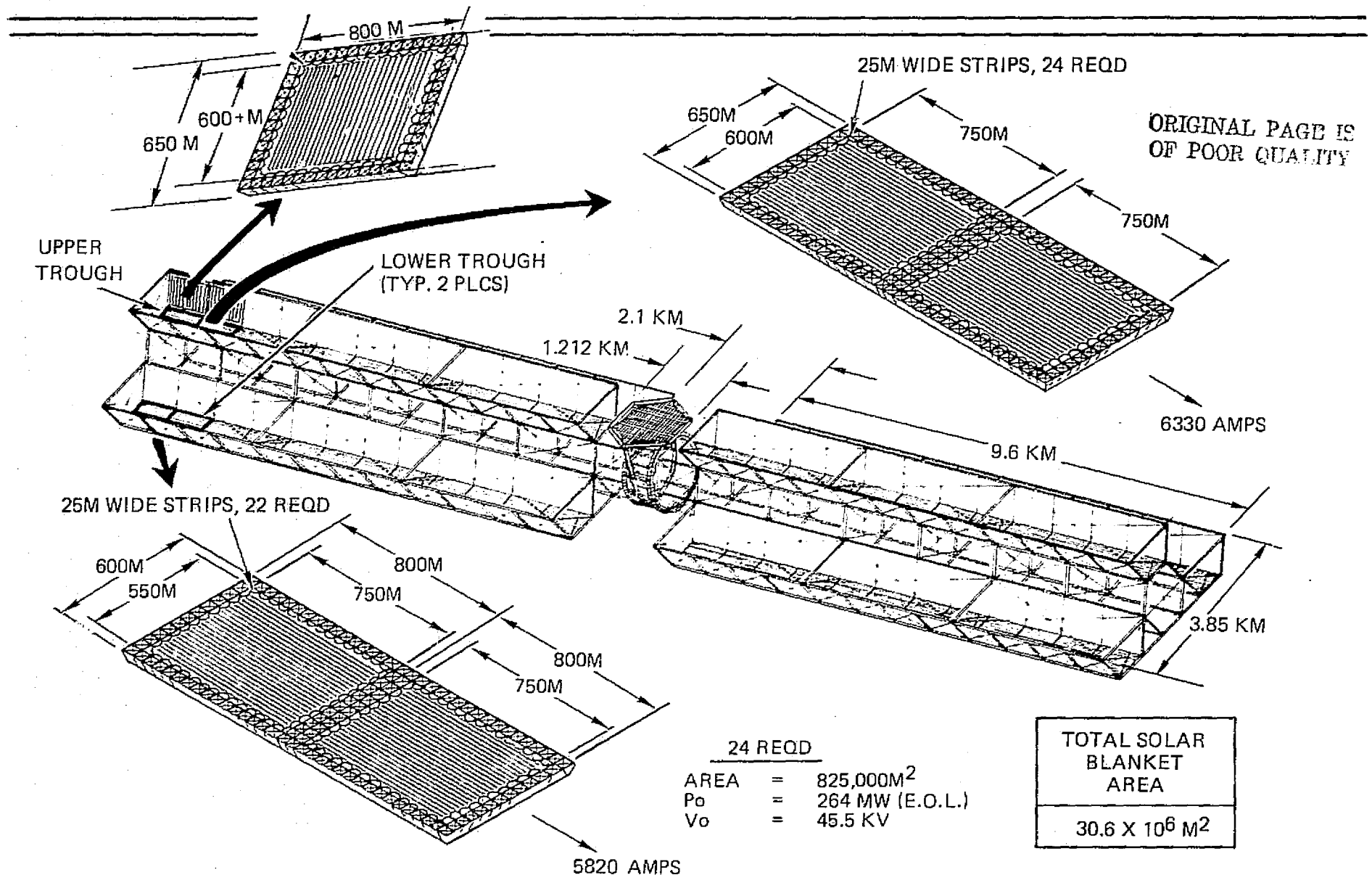
●	LOAD LOGISTICS VEHICLE (LV) AT WAREHOUSE	
●	DEPART WAREHOUSE FOR FABRICATOR, DOCK.	0.5
●	CONNECT LV TO TBF CONTROL BOX	0.1
●	POSITION BEAM MACHINES	0.1
●	POSITION LV (3 TIMES @ 0.1 EACH)	0.3
●	UNLOAD/LOAD CASSETTES (6 LOCATIONS)	6.0
●	UNLOAD/LOAD FITTING MAGAZINE	0.4
●	POSITION LV FOR DEPARTURE	0.1
●	RETURN TO WAREHOUSE	0.5
		8.0 HRS



SOLAR CONVERTER CONFIGURATION

This perspective shows the location of the solar blankets and reflectors in the three troughs. Both reflectors and blanket strips are attached to the satellite structure by catenaries as indicated in the details and will be further described in subsequent charts.

SOLAR CONVERTER CONFIGURATION



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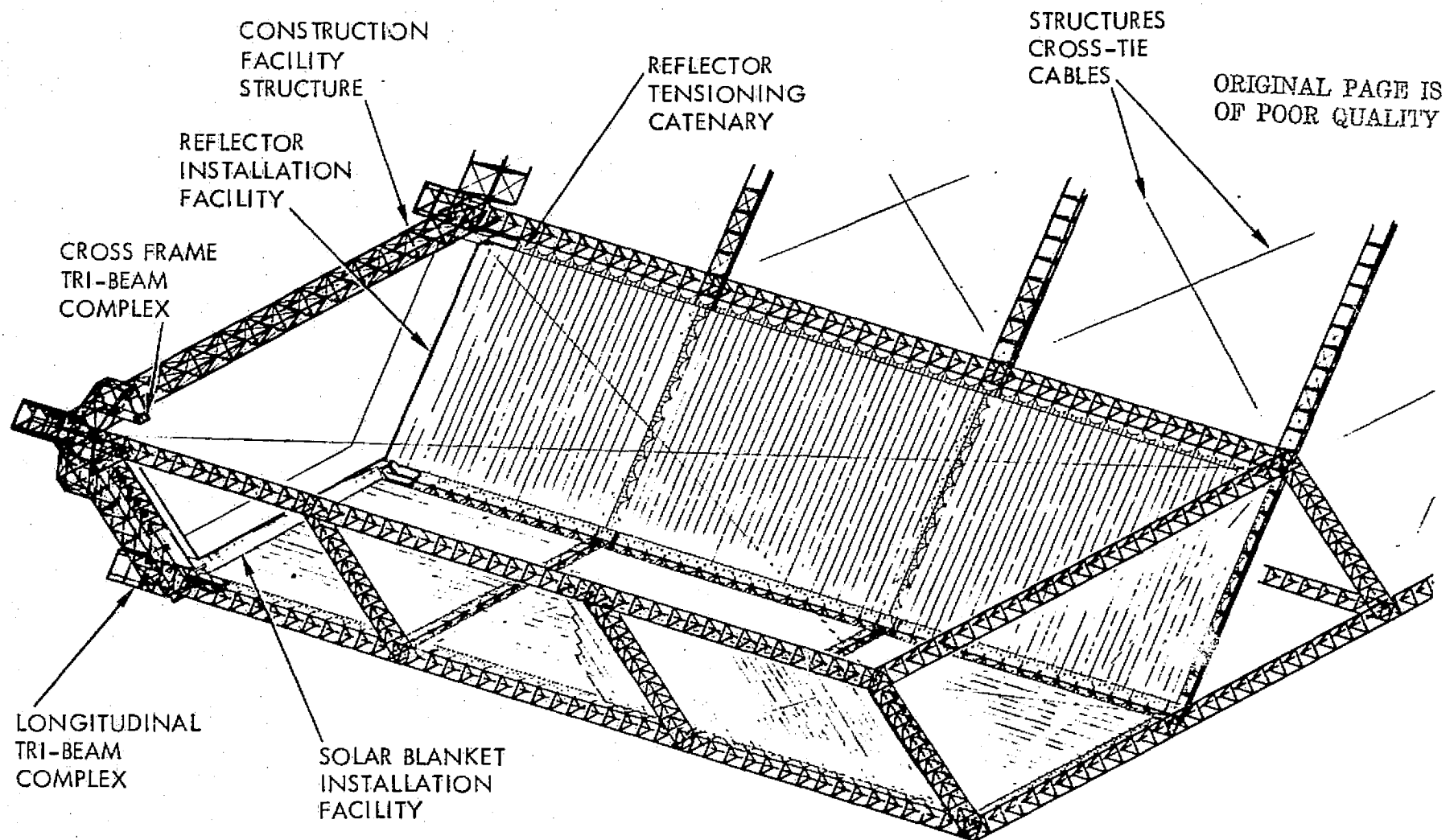
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SOLAR CONVERTER CONSTRUCTION
(Structures, Solar Blankets and Reflectors)

The perspective drawing illustrates the near-completion of the first three 800-meter "bays" in the lower corner of the satellite with a section of the outside reflector panels cutaway. It can be seen that the solar blankets are laid out in horizontal strips but that the reflector panels are vertically oriented. The structure of an 800-meter bay is estimated to take one 8-hour shift to fabricate. During this time, the solar blankets are "played out" - from 25-meter rolls - and edge-attached to longitudinal lines of composite materials; the reflectors are refurled (to be shown later) and also loosely constrained by vertical lines. Upon reaching the end of a bay, the construction facility is stopped and, during the next five 8-hour shifts, the cross frame members are attached, the solar blankets are secured and the reflector panels are tensioned.

SOLAR CONVERTER CONSTRUCTION

(STRUCTURES, SOLAR BLANKET & REFLECTORS)

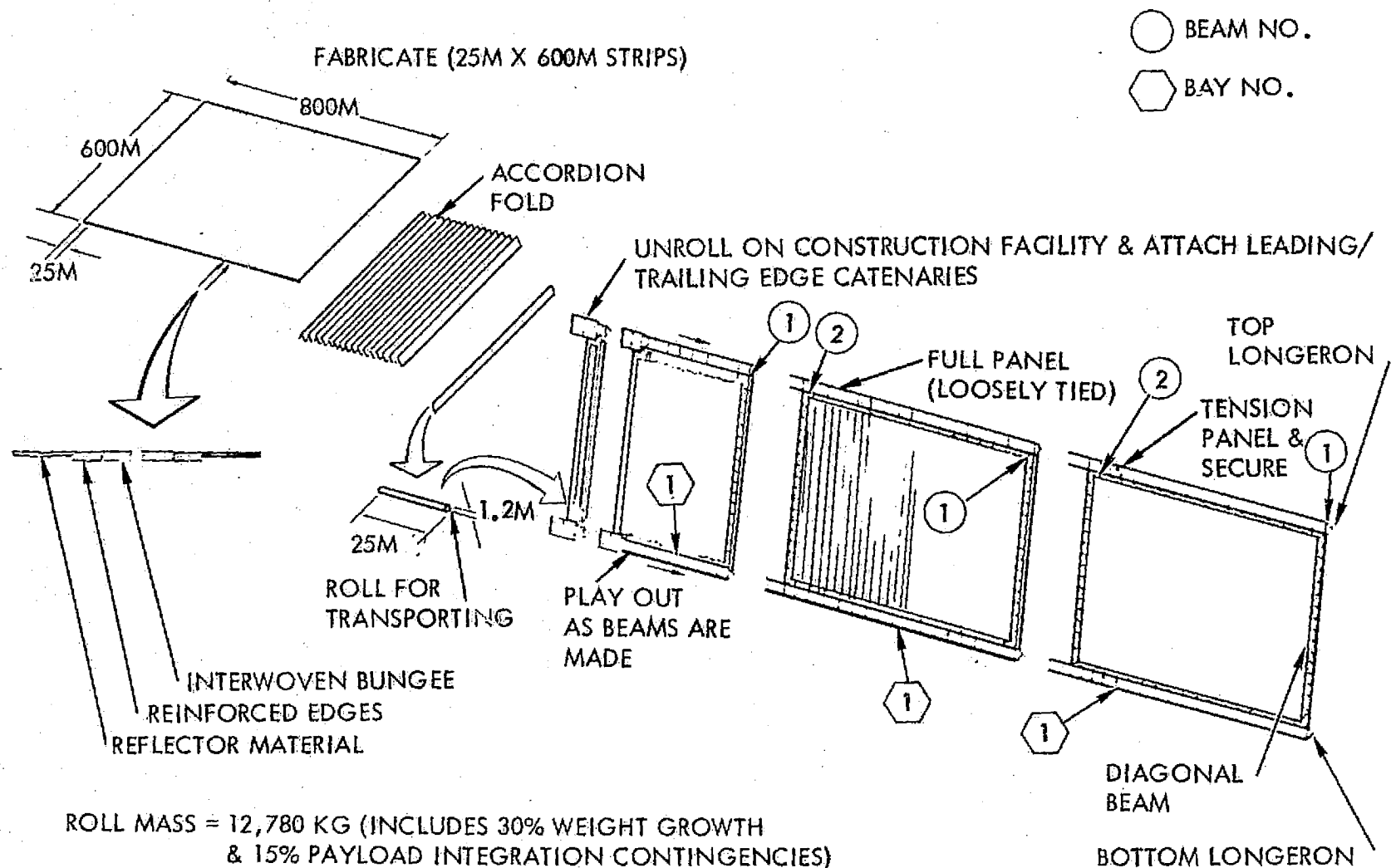


REFLECTOR PACKAGING AND INSTALLATION

The reflector panels, measuring 600-m $\times$ 800-m, are pleated at 25-m intervals to produce an accordin type fold as shown. They are then rolled along the plane of the end pleat into a roll 25-m long and 1.2-m diameter which is the configuration for transporting into orbit.

When installed, each reflector panel is suspended within the 800-m bay by longitudinal catenaries attached to the upper and lower longerons and by leading and trailing edge catenaries attached to the forward and aft diagonal members of the transverse frames. The catenaries are attached to the trailing and leading diagonal transverse beams and to the longerons. Two panels are required for each 800-m bay of each trough or a total of 144 panels for the entire satellite.

REFLECTOR PACKAGING & INSTALLATION



ROLL MASS = 12,780 KG (INCLUDES 30% WEIGHT GROWTH
& 15% PAYLOAD INTEGRATION CONTINGENCIES)

NO. ROLLS=144

SOLAR BLANKET INSTALLATION CONCEPT

The solar blanket in each 800 m long bay is a structurally independent installation suspended by side and end catenaries attached to the longerons and cross beams respectively, and by longitudinal cables stretched between the blanket strips. Each blanket strip is approximately 25 m wide and 750 m long, and is packaged in a 25 m wide roll by 0.6 m in diameter. Each two bays of solar blankets are electrically connected in series, constituting a functional module which produces the required voltage.

Initially the blanket rolls are transported from the SCB warehouse area by a transporter/loader (①) which inserts the rolls into the dispensers (⑥). The leading edge of the blanket strips with end catenaries attached, are then threaded through the roller arrangement and attached to the trailing edge of the cross beam just completed. The longitudinal cables to which the side edges of the blanket will be fastened are threaded from the cable dispenser (⑬) and attached in a similar manner. The longitudinal catenaries are fabricated on the middle deck, fed into the dispensing spindle (⑮) and then attached to the cross beam trailing edge.

Solar blankets and catenaries are attached to the longitudinal cables by fold-over tabs which are applied by automatic fastening equipment. As the cross beam advances the blanket strips, longitudinal catenaries cables are payed out. The two outside cables are attached to the longitudinal catenaries, the two longitudinal catenaries to their respective longerons, and the inside edges of adjacent blanket strips to their stabilizing cables. Upon completion of the bay and the next following cross beam, the trailing edges of the blankets (i.e., the trailing transverse catenaries) and the trailing end of the longitudinal catenaries are attached to the leading edge of that cross beam. The installation is then tensioned and electrical connections completed.

EQUIPMENT AND LOCATION DESCRIPTIONS

- ① S/A BLANKET ROLL TRANSPORTER - LOADER
- ② S/A BLANKET ROLLS
- ③ USED ROLL CORES
- ④ BLANKET ROLL INSTALLER - REMOVER
- ⑤ TRANSPORTER TRACKS
- ⑥ S/A BLANKET DISPENSING SPINDEL QUAD
- ⑦ BLANKET STRIP GUIDE ROLLERS
- ⑧ DEPLOYED SOLAR BLANKET STRIP
- ⑨ LEADING TRANSVERSE CATENARY
- ⑩ BLANKET STRIP - TRANSVERSE CATENARY JOINT LINE
- ⑪ UPPER VERTEX OF SATELLITE (50 M TRIBEAM GIRDER) CROSS BEAM
- ⑫ TRANSVERSE-CATENARY-TO-CROSS BEAM ATTACH POINT
- ⑬ LONGITUDINAL CABLE DISPENSER
- ⑭ LONGITUDINAL CABLE
- ⑮ LONGITUDINAL CATENARY DISPENSING SPINDEL
- ⑯ LONGITUDINAL CATENARY ROLL
- ⑰ UPPER VERTEX OF SATELLITE (50 M TRIBEAM GIRDER) LONGERON IN
BOTTOM CORNER OF TROUGH
- ⑱ BLANKET-EDGE-TO-CABLE ATTACH MACHINE
- ⑲ BLANKET-EDGE-TO-LONGITUDINAL CATENARY ATTACH MACHINE
- ⑳ DEPLOYED LONGITUDINAL CATENARY
- ㉑ CATENARY-TO-LONGERON ATTACH POINT
- ㉒ SWITCH GEAR MOUNTED ON CROSS BEAM



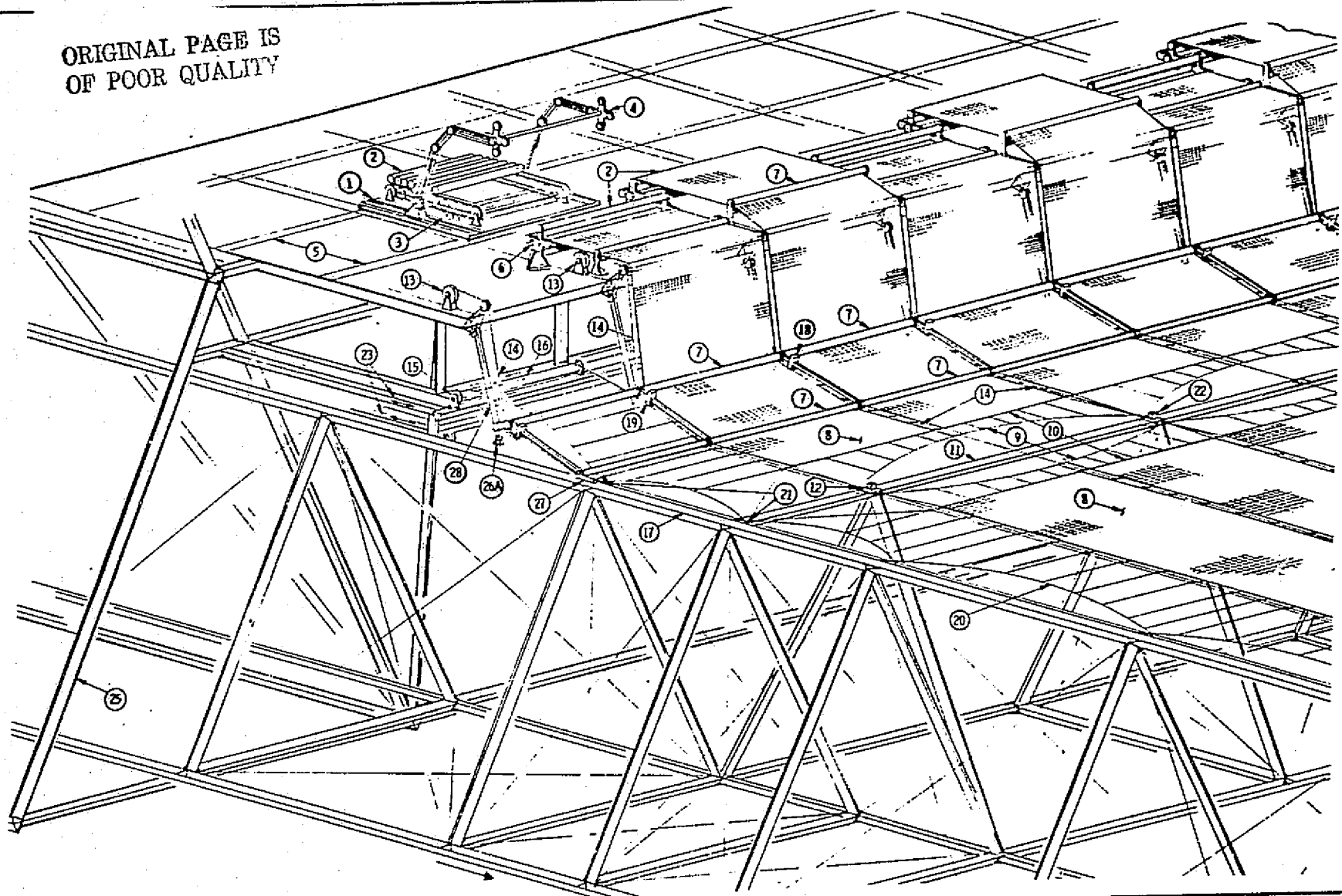
EQUIPMENT AND LOCATION DESCRIPTIONS (CONT.)

- ②③ RETRACTING PLATFORM FOR SWITCH GEAR AND SECONDARY FEEDER INSTALLATION
- ②④ MAIN FEEDER DISPENSER
- ②⑤ CONSTRUCTION FIXTURE
- ②⑥ TRANSVERSE CATENARY-TO-CROSS BEAM ATTACH MACHINE IN ATTACH POSITION; 26A NON-ATTACH POSITION
- ②⑦ LONGITUDINAL CATENARY-TO-LONGERON ATTACH MACHINE IN ATTACH POSITION; 27A NON-ATTACH POSITION
- ②⑧ ATTACH EQUIPMENT TRANSLATING SUPPORT ARM
- ②⑧A TRANSLATING ARM IN CATENARY-TO-CROSS BEAM ATTACH POSITION
- ②⑨ CROSS BEAM (50 M TRIBEAM GIRDER) FABRICATION FACILITY IN BEAM FABRICATION POSITION
- ②⑨A 50 M CROSS BEAM IN FABRICATION POSITION



SOLAR CELL BLANKET INSTALLATION CONCEPT

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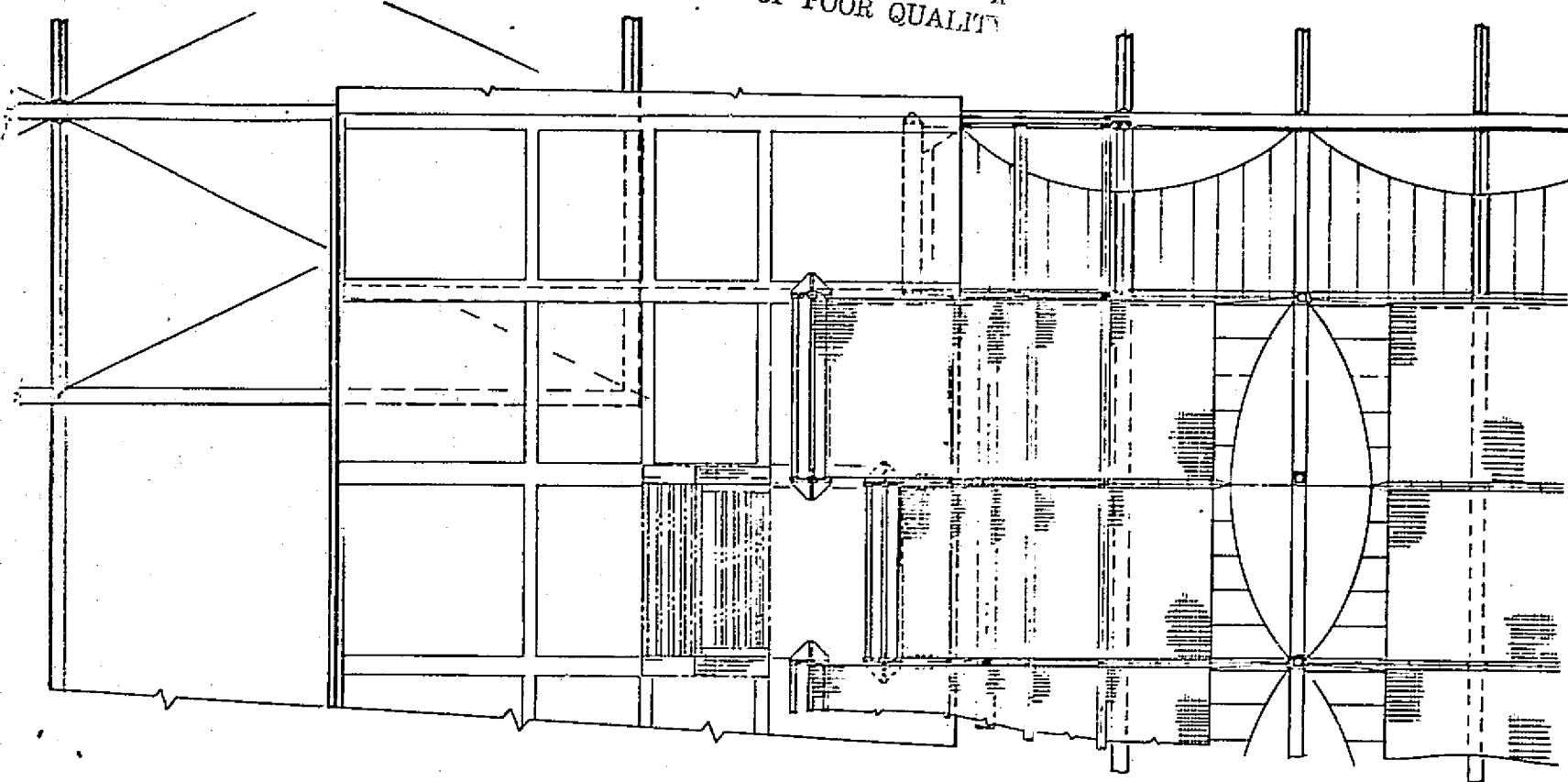
SOLAR BLANKET STATION PLAN

This is a (partial) plan view of the upper deck solar blanket installation station. It shows the transporter/loader in position to service a dispenser. The dispensers are staggered to prevent interference between adjacent stations.

A leading edge and trailing edge catenary is shown in the right portion of the chart. A single 50 m wide catenary connects each two blanket strips to the cross beam. The longitudinal catenary which provides attachment and tensioning to the longerons also is shown.

BLANKET INSTALLATION STATION PLAN

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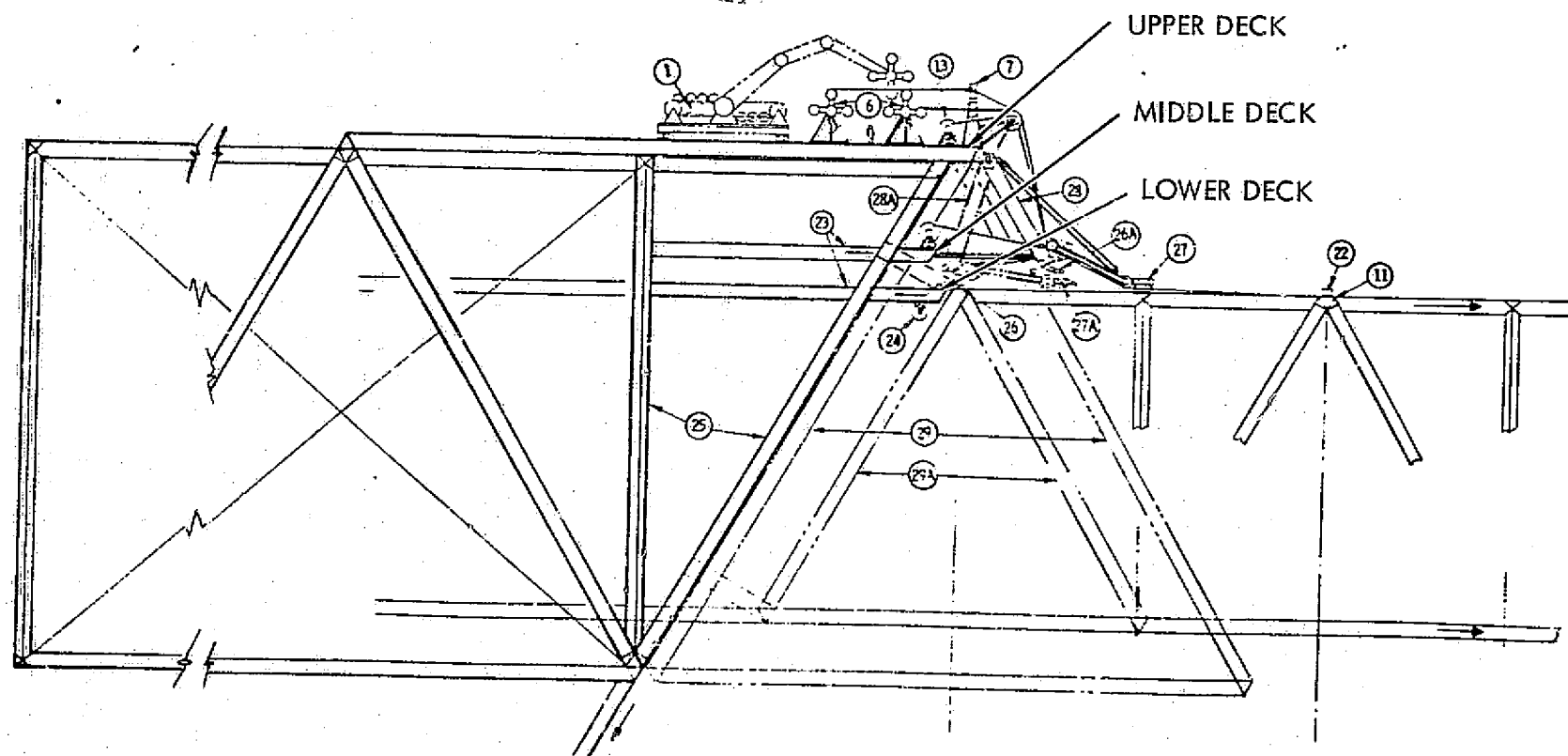
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BLANKET INSTALLATION STATION ELEVATION

This elevation shows the position of the upper, middle, and lower deck with respect to the tribeam fabricators (25 , 29), together with the location of the various loading and dispensing devices. The longitudinal beam is advancing to the right as it is constructed. A portion of a completed crossbeam (11) is shown. The next crossbeam (29A) is in the fabrication position. The activity which takes place at each of the deck stations is described in more detail on the next chart.

BLANKET INSTALLATION STATION ELEVATION

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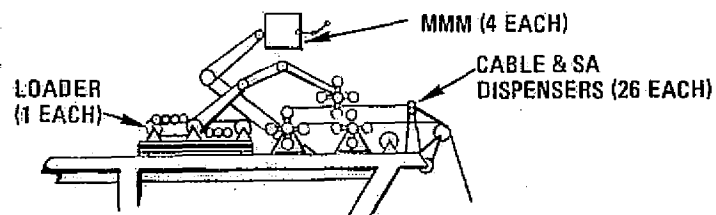
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MANNED OPERATIONS AT SOLAR BLANKET INSTALLATION STATIONS

The primary operations occurring at the upper, middle, and lower deck stations during beam fabrication and solar blanket installation are identified. The locations of the manned manipulator modules (MMM) required to support the installations also are shown. These modules are mounted on transverse tracks and are spaced so that each module services approximately one fourth of the 27 installation stations across the span of the crossbeam.

MANNED OPERATIONS AT SOLAR BLANKET INSTALLATION STATIONS

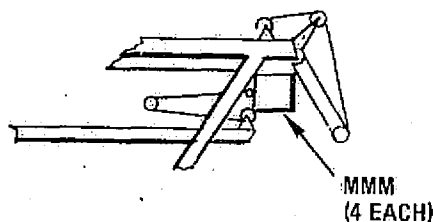
UPPER DECK



- DELIVER SA ROLLS TO LOADER
- LOADER INSERTS ROLLS IN DISPENSERS
- ROLLS THREADED THRU ROLLER SYSTEM
- DISPENSER MONITORING

4 MEN

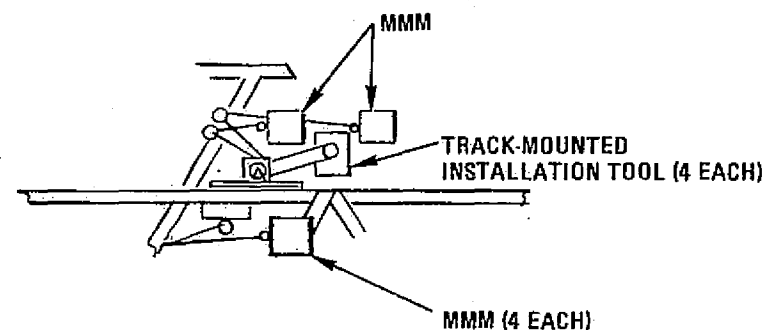
MIDDLE DECK



- FABRICATE & THREAD LONG CATENARY
- CATENARY/CABLE ATTACH MONITORING

4 MEN

LOWER DECK



- INSTALL SADDLE CLAMPS
- INSTALL SWITCH GEARS, SM & RAC ASSP
- INSTALL INSULATION MOUNTS
- ATTACH & TENSION SA'S
- INSTALL FEEDER & DM&C BUS
- MAKE ELECTRICAL CONNECTIONS

12 MEN



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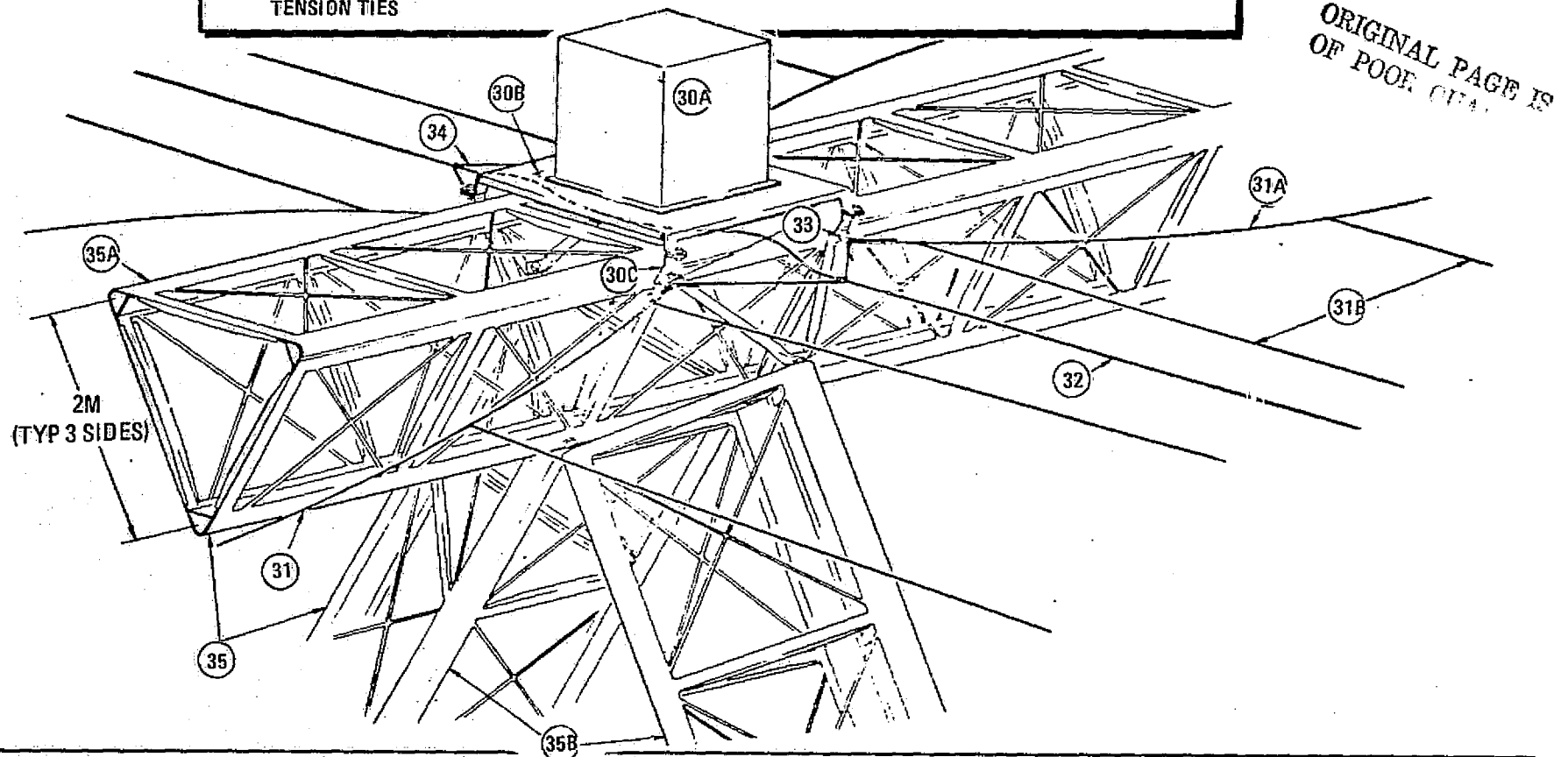
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INSTALLATION OPERATIONS AT CROSSBEAMS

Switch gear assemblies, secondary power feeders, DM&C elements sub-multiplexers and remote acquisition and control (RAC) units and DM&C buses are located on the crossbeams at the ends of the blanket strips. Alternate crossbeams mount 25 and 13 switch assemblies respectively. Saddle clamps are attached to the crossbeams at 25 m intervals to coincide with the blanket strip edges. The saddle clamp assemblies provide connectors for attachment and tensioning of cables and catenaries, mounting provisions for secondary feeder insulators, and a saddle for support of the switch assemblies.

INSTALLATION OPERATIONS AT CROSSBEAMS

- | | | | |
|-----|---|-----|---|
| 30 | SWITCH GEAR ASSY | 32 | LONGITUDINAL SOLAR BLANKET RESTRAINING CABLES |
| 30A | SWITCH GEAR | 33 | CATENARY/SB CABLE ATTACH FITTINGS |
| 30B | INSTALLATION SADDLE | 34 | SB CABLE TENSIONING YOKE |
| 30C | MULTI-ATTACH BRACKET | 35 | CROSS BEAM AT ROUGH B
(50-M TRI-BEAM GIRDER) |
| 31 | 50-M TRANSVERSE CATENARY ASSY | 35A | TOP CAP (2-M BASIC BEAM ELEMENT) |
| 31A | CATENARY | 35B | SIDE BEAM MEMBERS (50-M LONG) |
| 31B | CATENARY-TO-SOLAR-BLANKET
TENSION TIES | | |



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SOLAR CONVERTER CONSTRUCTION SEQUENCE TYPICAL BAY

OPERATION \ DAY SHIFT	1			2		
	1	2	3	1	2	3
<u>CONSTRUCT & INSTALL BAY N</u>						
FAB LONGERONS & DISPENSE SB'S & REFL'S BAY N						
FAB CB N + 1						
BEAM						
END FITTINGS						
ATTACH CB N + 1 TO LONGERONS						
ALIGN STRUCTURE						
RELOAD SOLAR BLNKT & REFL. DISPENSERS						
<u>INSTALL EQUIPMENT, MAKE ATTACHMENTS & TENSION AT CBN + 1</u>						
INSTALL HARDWARE						
ATTACH & TENSION BLANKETS						
INSTALL/CONNECT ELECT. PWR/DM&C BUSES						
CHECKOUT						



INSTALLATION OPERATIONS AT CROSS BEAMS

Upon completion of crossbeam structure fabrication the saddle clamps, switch assemblies and DM&C equipment are the first items to be installed. Secondary feeders and their insulation mounts are included in this installation for alternate crossbeams. The SB trailing edge catenaries and longitudinal cable tensioning ties are then attached, followed by tensioning and clamping of the transverse catenaries and longitudinal cables. Following this operation, the leading edges of the SB transverse catenaries are attached to the trailing edge of the crossbeam by means of the brackets installed on the saddle. The operation at each station is completed by attaching the SB connectors to the switch assemblies, connecting the DM&C elements to the DM&C bus, and connecting the switch gears to secondary feeders (alternate crossbeams). Construction of the longerons and crossbeams for the next bay is then initiated.

INSTALLATION OPERATIONS AT CROSSBEAMS

HOURS				
0	4	8	12	16

INSTALL & ATTACH HARDWARE

- SADDLES
- SWITCH GEAR
- SM/RAC ASSYS
- TENSION CABLES
- INSULATION MOUNTS*
- D&C BUS
- SEC. FEEDERS*

ATTACH & TENSION SOLAR ARRAY BLANKETS

- TR. EDGE OF DEPLOYED BLANKET TO CROSSBEAM LEAD. EDGE
- TR. EDGE CATENARY - TENSION & CLAMP
 - SB CABLES - TENSION & CLAMP
 - THREAD SA BLANKET
 - LEAD. EDGE OF NEXT BLANKET TO CROSSBEAM TRAIL. EDGE

ELECTRICAL INSTALLATION AND CONNECTION

- SB PWR LEAD CONNECTORS TO SWITCH GEAR
- SWITCH GEAR TO SECONDARY FEEDER*
- SECONDARY FEEDER TO MAIN FEEDER*
- DM&C CONNECTORS TO SM/RAC ASSY'S
- SM/RAC ASSY'S TO D&C BUS

* ALTERNATE CROSS BEAMS

C/O



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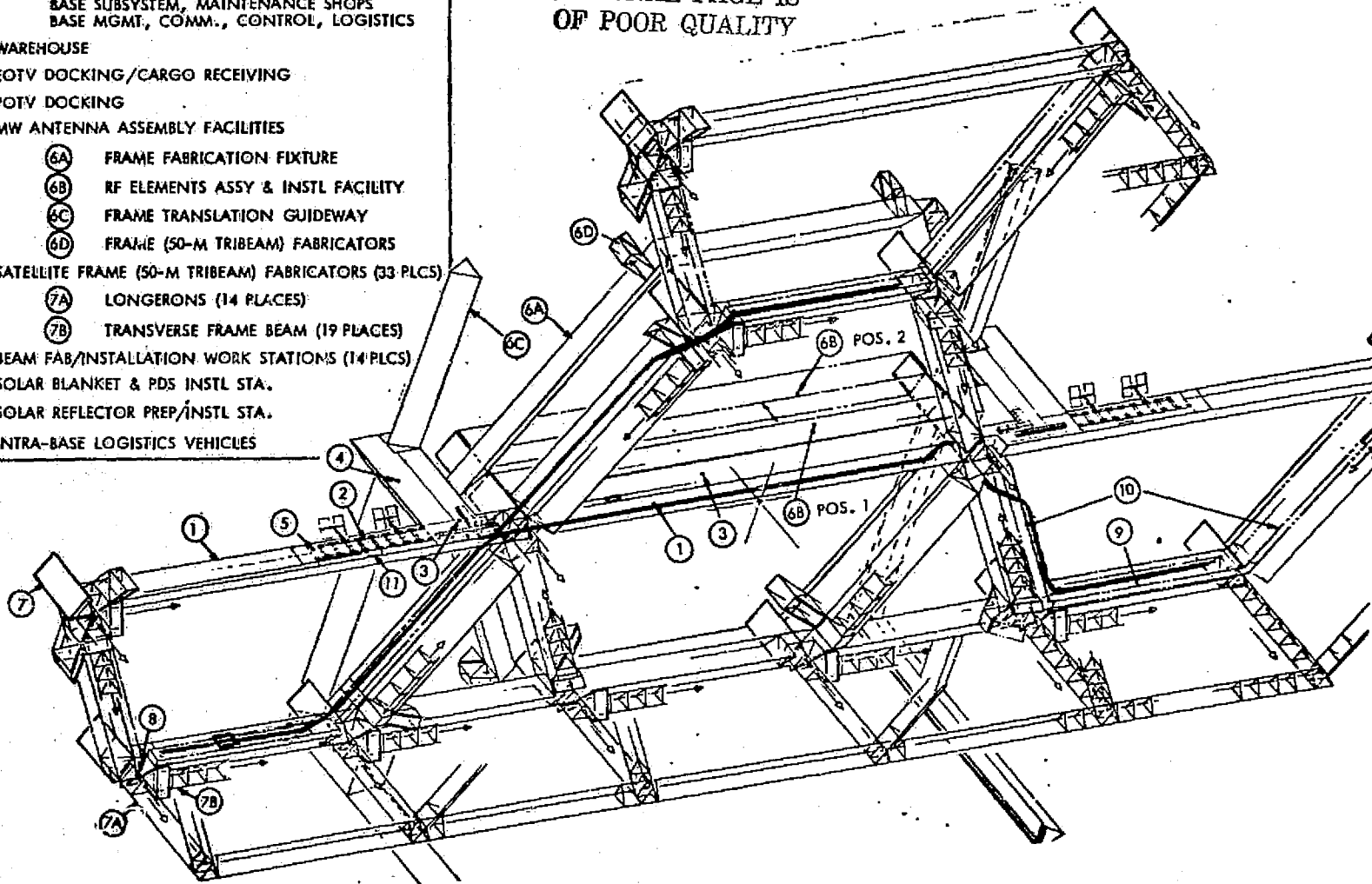
SATELLITE CONSTRUCTION BASE (SCB)

Twenty-two solar blanket strips are required for the lower trough of each bay and twenty-four strips for the upper trough of each bay. A total of sixty-eight blanket rolls must be delivered to the three locations prior to the start of the next bay construction. A logistics vehicle capable of transporting up to twenty-four blanket rolls while traveling on tracks was selected for this purpose. The chart shows the general location of the tracks originating at the warehouse area and proceeding to the three loading locations.

SATELLITE CONSTRUCTION BASE (SCB) (GEO Located)

- ① CONSTRUCTION FIXTURE
- ② BASE SUPPORT FACILITIES & EQUIP (2 EA)
340-CREW MEMBER SUPPORT
BASE SUBSYSTEM, MAINTENANCE SHOPS
BASE MGMT, COMM., CONTROL, LOGISTICS
- ③ WAREHOUSE
- ④ EOTV DOCKING/CARGO RECEIVING
- ⑤ POTV DOCKING
- ⑥ MW ANTENNA ASSEMBLY FACILITIES
 - ⑥A FRAME FABRICATION FIXTURE
 - ⑥B RF ELEMENTS ASSY & INSTL FACILITY
 - ⑥C FRAME TRANSLATION GUIDEWAY
 - ⑥D FRAME (50-M TRIBEAM) FABRICATORS
- ⑦ SATELLITE FRAME (50-M TRIBEAM) FABRICATORS (33 PLCS)
 - ⑦A LONGERONS (14 PLACES)
 - ⑦B TRANSVERSE FRAME BEAM (19 PLACES)
- ⑧ BEAM FAB/INSTALLATION WORK STATIONS (14 PLCS)
- ⑨ SOLAR BLANKET & PDS INSTL STA.
- ⑩ SOLAR REFLECTOR PREP/INSTL STA.
- ⑪ INTRA-BASE LOGISTICS VEHICLES

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SB TRANSPORT AND LOADING TIMELINE

● LOAD TRANSPORTER AT WAREHOUSE	ON-GOING
● TRANSPORT TO SB INSTALLATION STATION	0.7
● LOAD 26 SB DISPENSERS ($\approx$ 15 MIN./DISP.)	6.4
● TRANSPORTER RETURN TO WAREHOUSE	<u>0.9</u>
	8.0 HRS

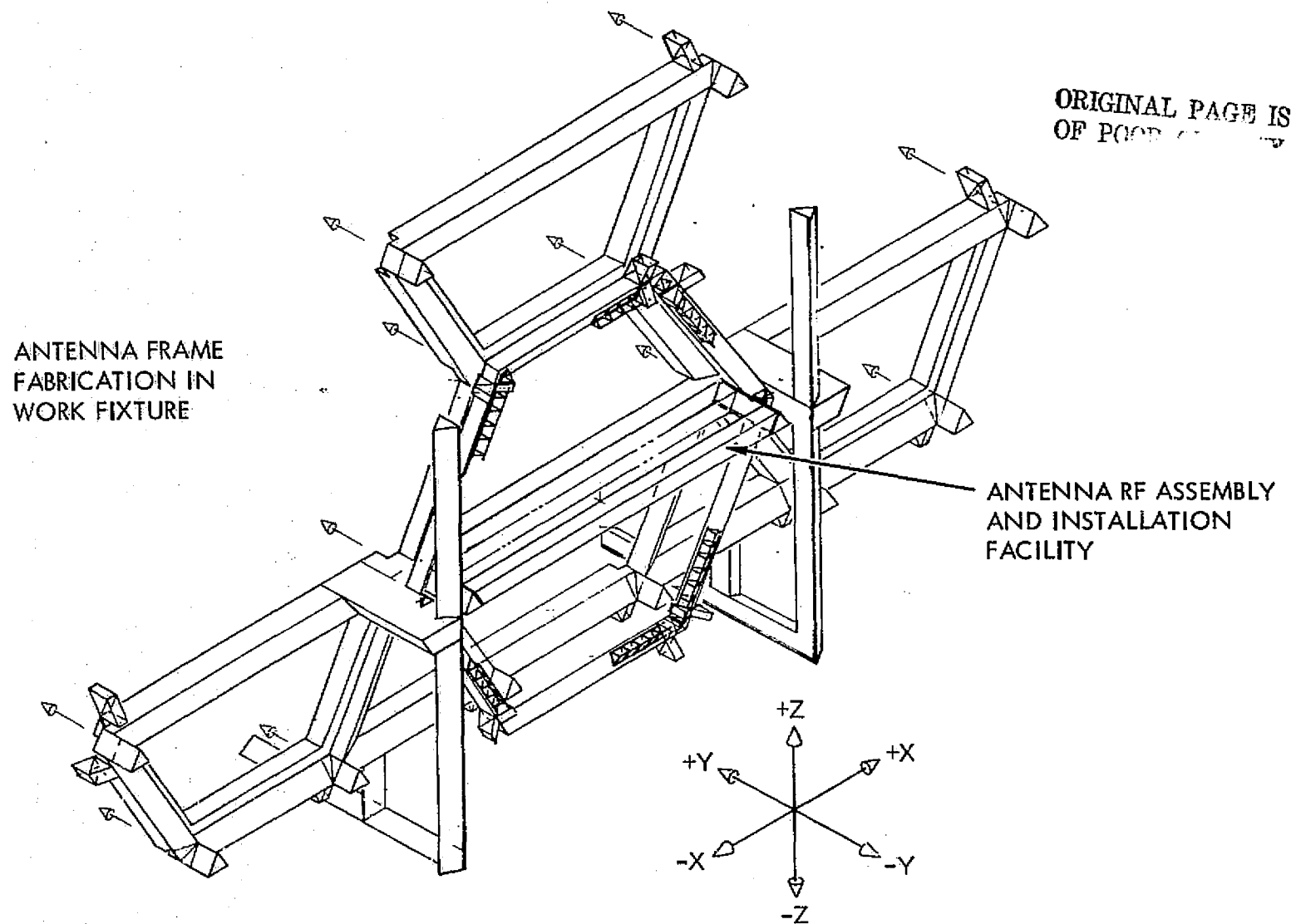


MW ANTENNA CONSTRUCTION/TRANSLATION SHEET 1

The microwave antenna is constructed concurrently with the first wing and then translated and rotated into its final position on the rotary joint. The partially completed antenna is shown on its dedicated hexagonal work fixture located on the (otherwise) inactive side of the SCB.

Beam machines located at each corner of the hex fixture produce the antenna frame. The antenna corners elements are constructed initially, followed by the connecting beams. The catenary cables and suspension web upon which the antenna RF elements are subsequently mounted is then installed. A dedicated facility for assembly and installation of antenna RF elements is also shown.

MW ANTENNA CONSTRUCTION/TRANSLATION - SHEET 1



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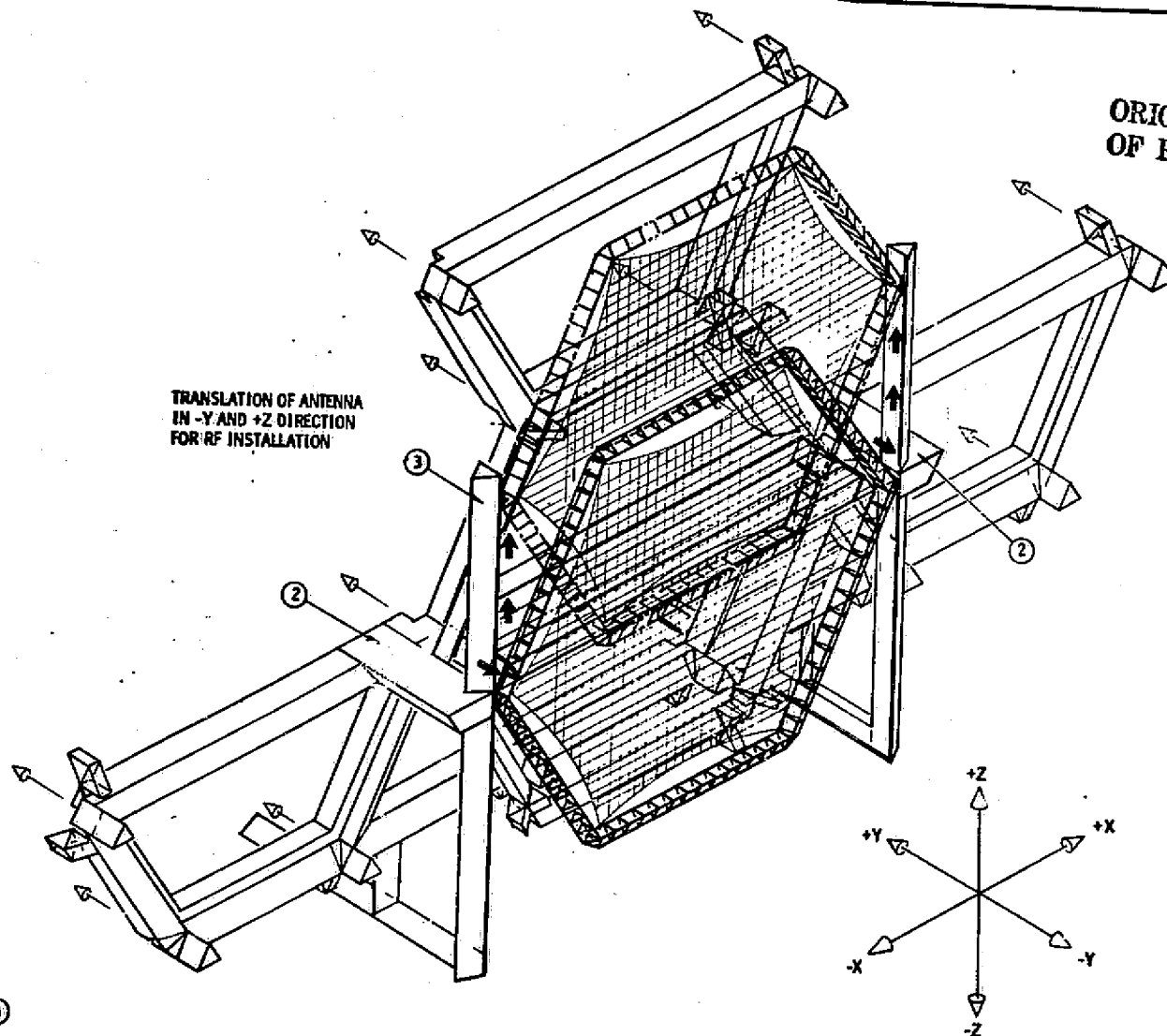
MW ANTENNA CONSTRUCTION/TRANSLATION SHEET 2

The antenna with installed catenaries and tension web is shown at two positions in the work fixture. Two track-mounted vehicles on opposite sides of the frame connected by a closed loop cable conveyor are utilized to deploy and install the cables. Upon completion of the tension web installation, the RF elements are installed. This concept entails translation of the antenna past a work platform which provides access to the antenna surface. The antenna is first translated in the -Y and +Z direction. The work platform is then extended in the -Y position to bring it into close proximity to the antenna face. With the work platform positioned, the antenna is translated in the -Z direction. The RF elements are installed as the antenna passes the platform.

MW ANTENNA CONSTRUCTION/TRANSLATION - SHEET 2

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TRANSLATION OF ANTENNA
IN -Y AND +Z DIRECTION
FOR RF INSTALLATION



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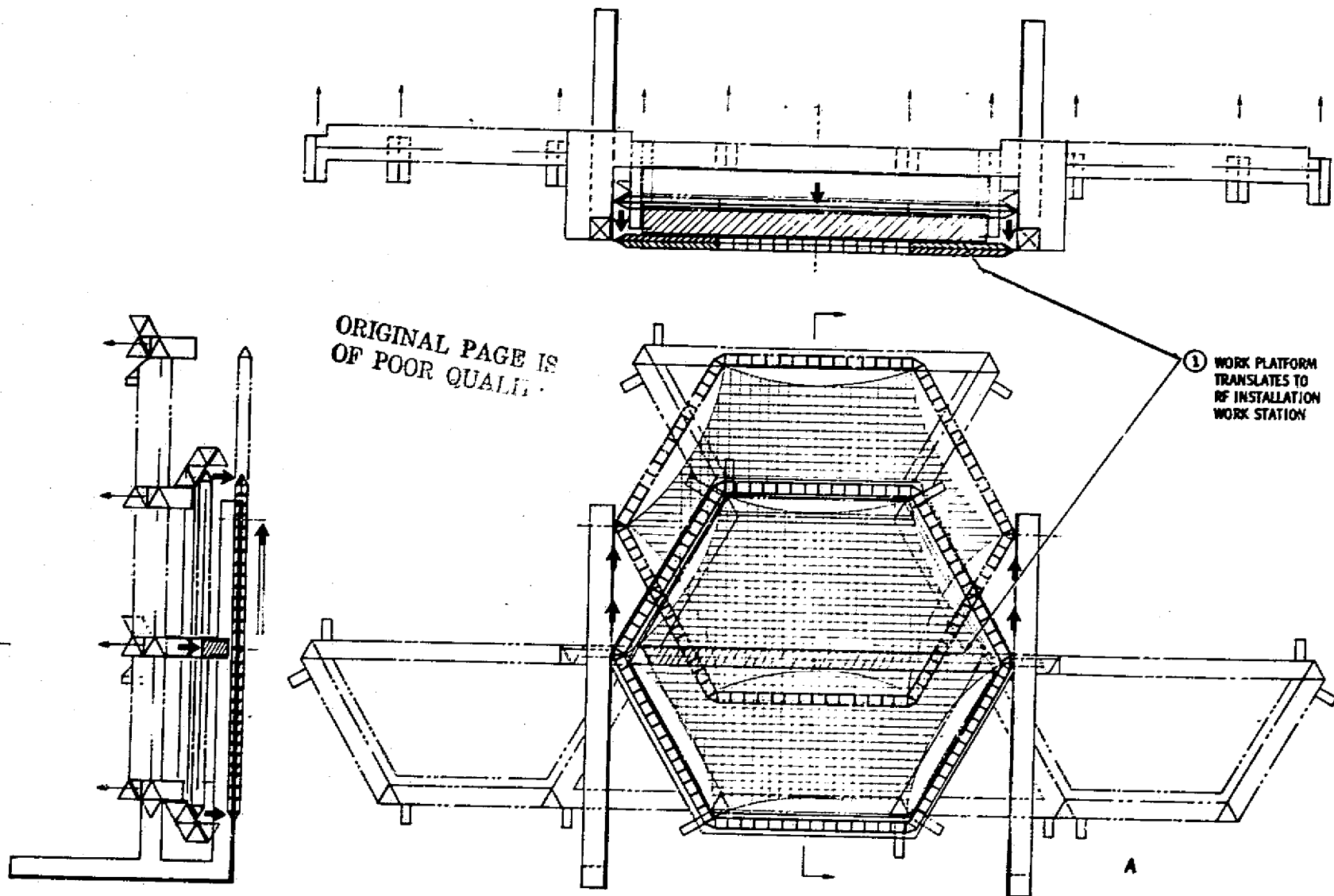
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MW ANTENNA CONSTRUCTION/TRANSLATION SHEET 3

These views show additional details of the translation process
and the work platform extension.

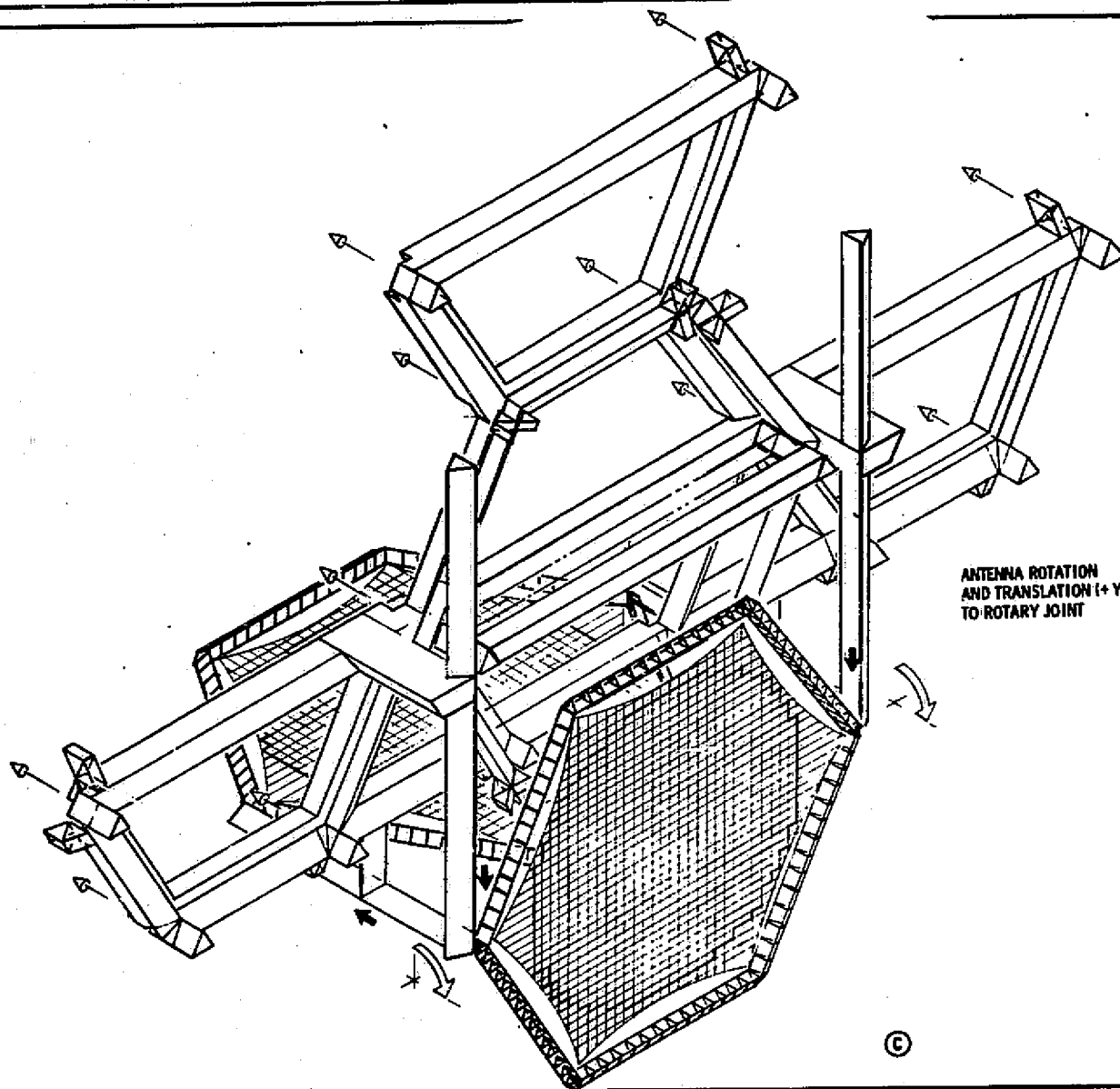
MW ANTENNA CONSTRUCTION/TRANSLATION - SHEET 3



MW ANTENNA CONSTRUCTION/TRANSLATION SHEET 4

The completed antenna is translated via the track system indicated to position B which places it over its mounting trunions on the rotary joint. (Completion of the antenna occurs simultaneously with completion of the rotary joint.) When the RF installation is completed, the antenna has been translated in the -Z direction to the end of the translation track. It is then rotated and translated in the +Y direction for attachment to the rotary joint. A key element in the transfer/installation operations is the minimal distance through which the completed antenna is moved.

MW ANTENNA CONSTRUCTION/TRANSLATION - SHEET 4



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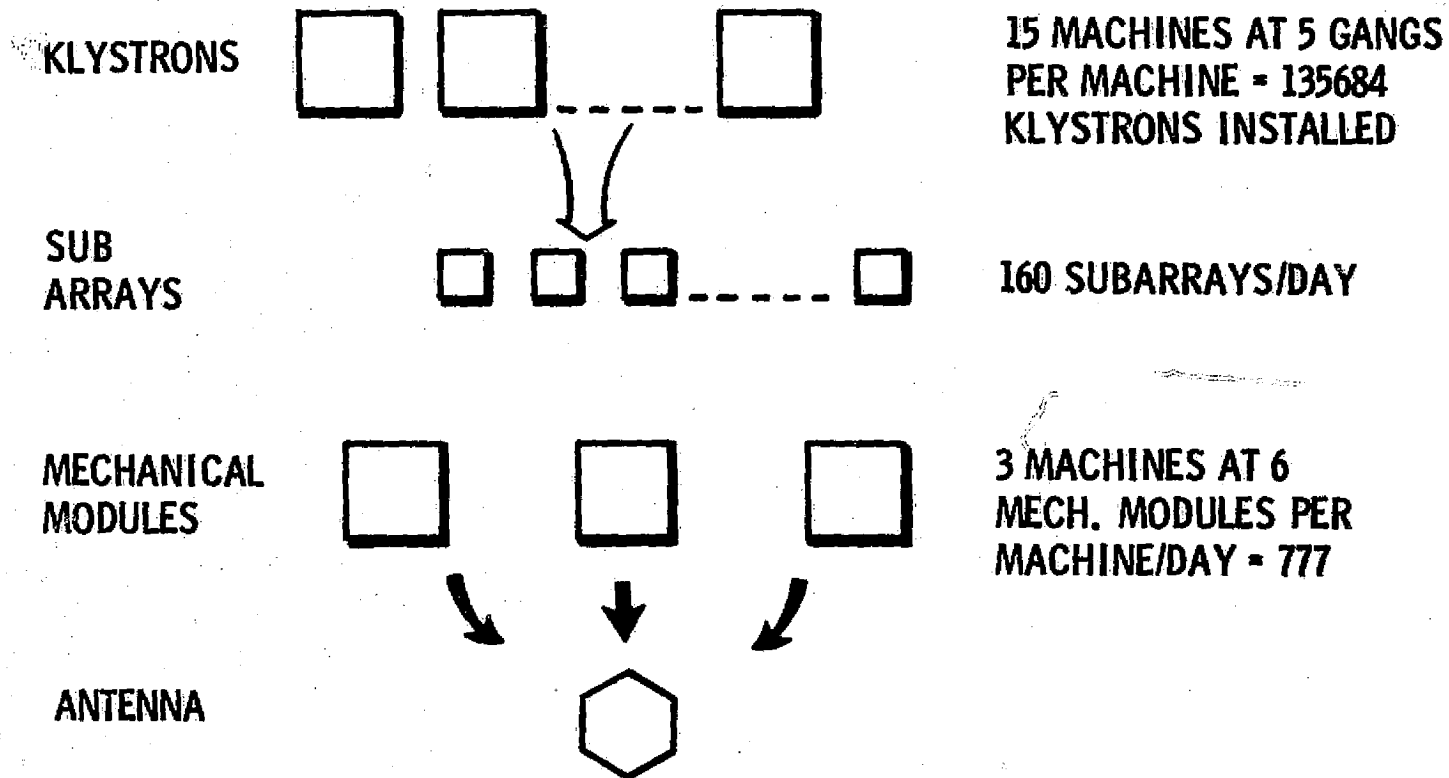
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ANTENNA RF ELEMENTS PROCESSING

- INSTALLATION TIME - 60 DAYS
- INSTALLATION RATES ADJUSTED FOR 50% DOWNTIME



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MW ANTENNA INSTALLATION CONCEPT

The rf assembly and installation facilities and sequence of operations are depicted in the next three charts. The antenna waveguide subarray panels, klystrons, and electronic modules are delivered to the rf assembly and installation facility, Item 6B, in the packaged configurations. A matrix identifying installation location on the antenna suspension web for each mechanical module by file and row number is given in View A. The rf assembly and installation facility, 6B, is behind the antenna in View A. View B, looking down from the top edge of the antenna, shows that the rf facility is supported at each end from the satellite fabrication fixture structure, and that it spans the full width of the antenna. The numbers across the top surface of the facility indicate the locations of 15 identical work stations for processing the incoming rf elements preparatory to assembly into the 30.6-m $\times$ 34.92-m mechanical module configurations. The antenna frame with its module support web installed translates downward in its guideways, (6C) bringing each row sequentially in front of the rf facility.

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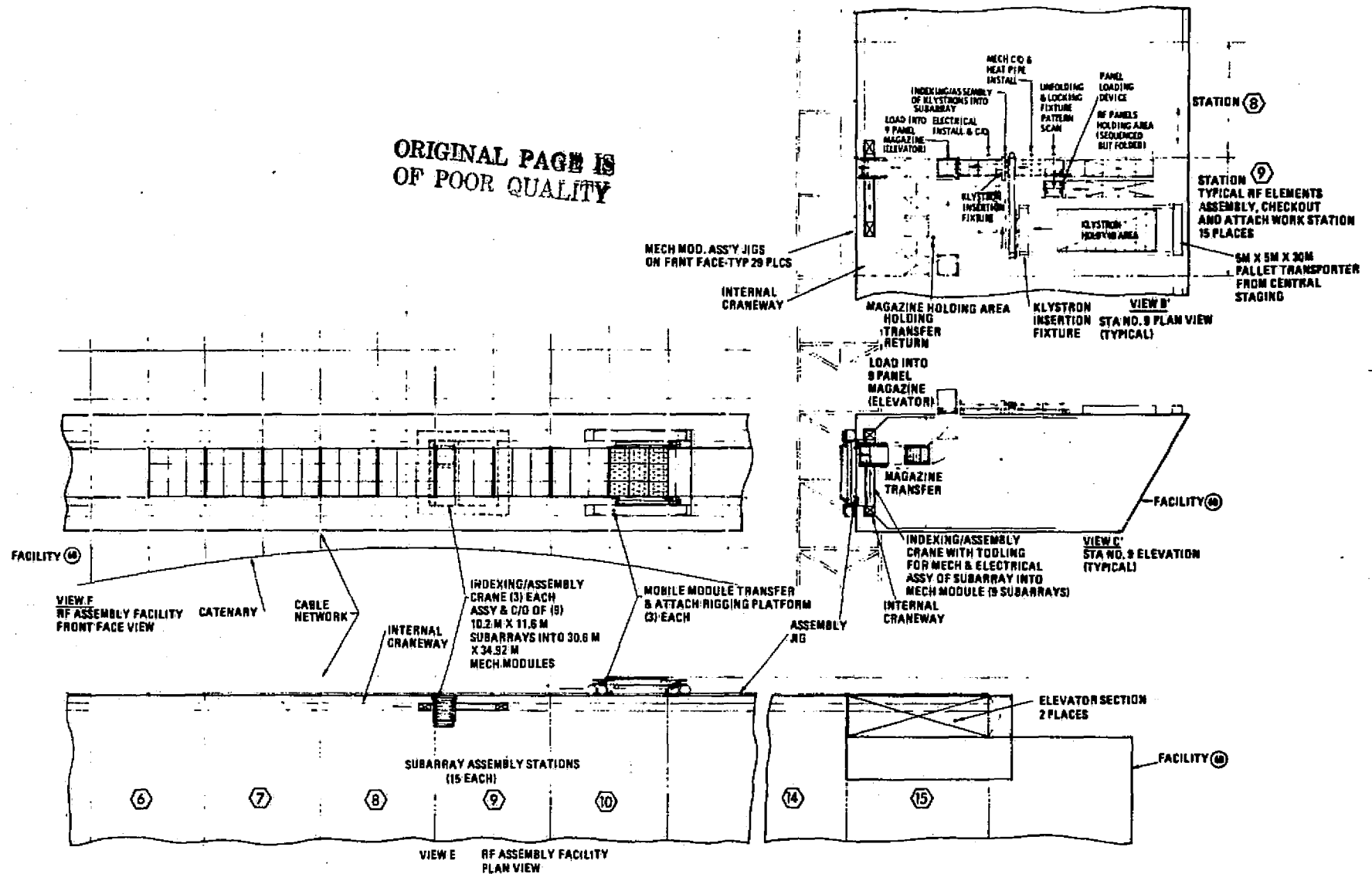
MW ANTENNA ASSEMBLY AND INSTALLATION FACILITY

Processing at the work stations is described in View B' and C', and the rate of processing to support the overall construction schedule is given on the following chart ("Antenna RF Processing"). The waveguide subarray panels are first unfolded to their operational surface dimensions of approximately 11-m $\times$ 10-m (the panels are about 0.26-m thick). They are then passed through the mechanical checkout station and klystron indexing/assembly station where the klystrons are automatically installed. The assembly of subarray and klystrons move to the electrical station where the electronic control boxes are installed, electrical connections are made, and the assembly is functionally checked out. These assemblies are loaded into the elevator magazine which transfers them (View C') down to the mechanical module indexing/assembly crane which operates on a craneway behind the front face of the facility (Views C', E and F). Jigs for assembly of the mechanical modules are located in the front face of the facility (Views C', E and F), one jig inline with each of the 29 files on the antenna. Each mechanical module is an assembly of 9 subarrays.

Three mobile module transfer and attach units travel the external front face of the rf facility with access to each module jig and to each antenna file (Views E and F). The module transfer units remove the completed modules from their assembly jig and transfer them straight across to their installation location on the web.

MW ANTENNA ASSEMBLY & INSTALLATION FACILITY

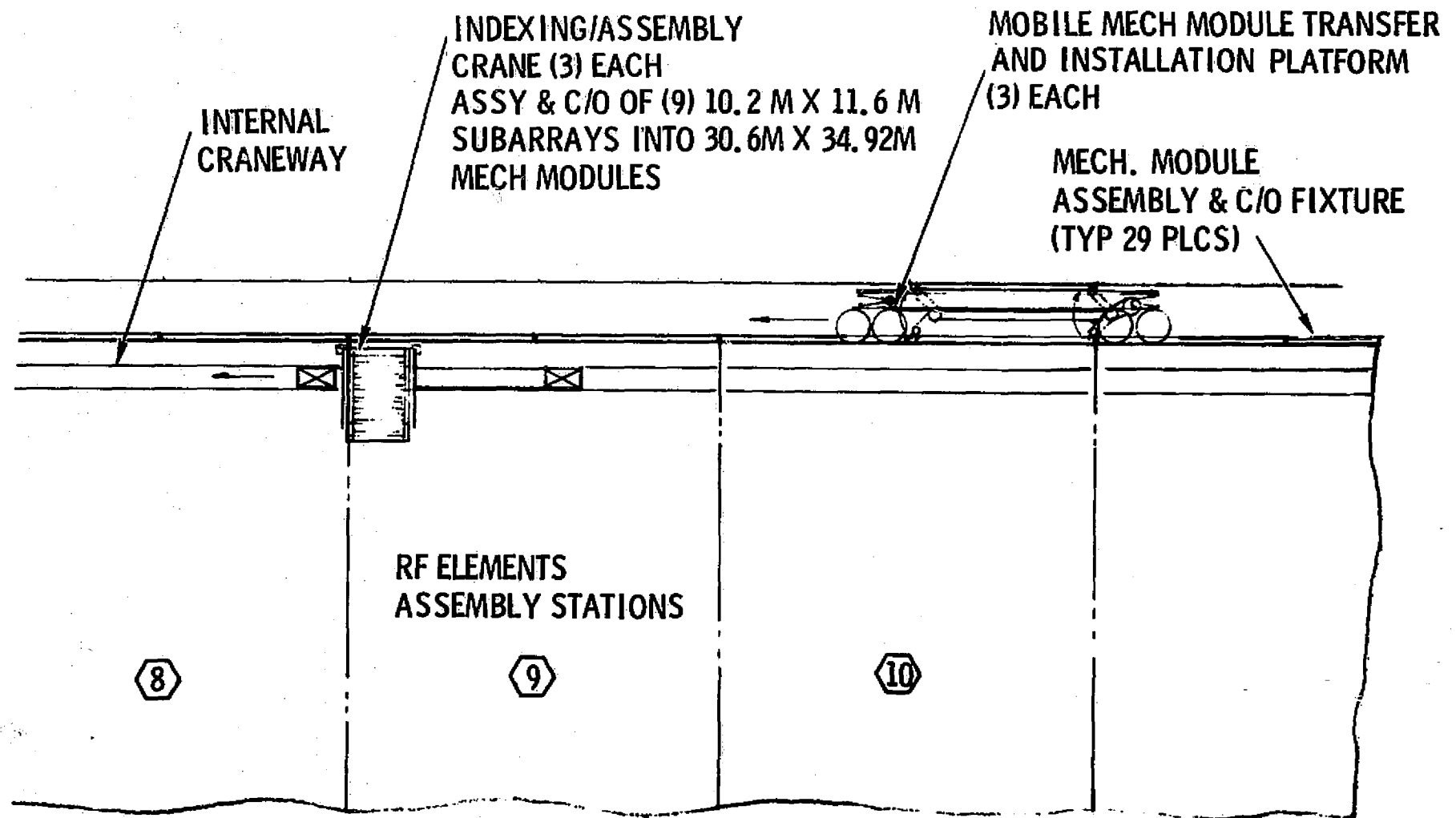
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PARTIAL PLAN VIEW OF RF ASSEMBLY FACILITY

This chart shows additional details of the indexing/assembly crane and the mobile mechanical module transfer and installation platform.

RF ASSY FACILITY
(PARTIAL PLAN VIEW)



MECHANICAL MODULE ASSEMBLY AND INSTALLATION STATION

This partial front face view shows the indexing/assembly crane, the mechanical module assembly and checkout fixture, and the mechanical module transfer and installation platform. The crane indexes the magazine to each of 9 sections of an assembly jig, installing a subarray in each, automatically making the connections and testing for mechanical module integrity. Three mobile module transfer and attach units remove the completed modules from their assembly jig and transfer them to the desired installation point on the antenna web, where they are installed, electrical connections made, and checked out.

MECHANICAL MODULE ASSEMBLY & INSTALLATION STATIONS

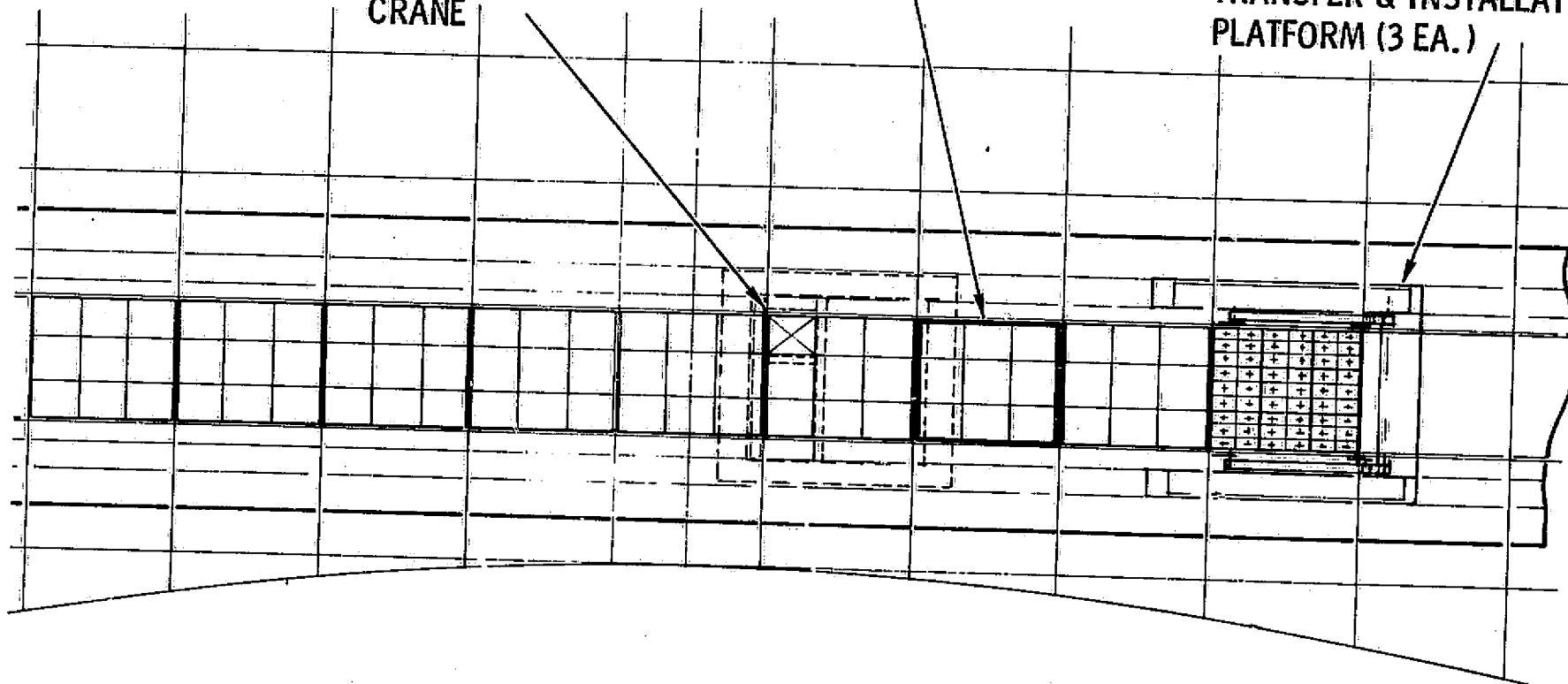
(PARTIAL FRONT FACE VIEW OF RF ASSY FACILITY)

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MECH. MODULE
ASSY & C/O FIXTURES
(TYP. 29 STATIONS)

INDEXING/ASSEMBLY
CRANE

MECH. MODULE
TRANSFER & INSTALLATION
PLATFORM (3 EA.)



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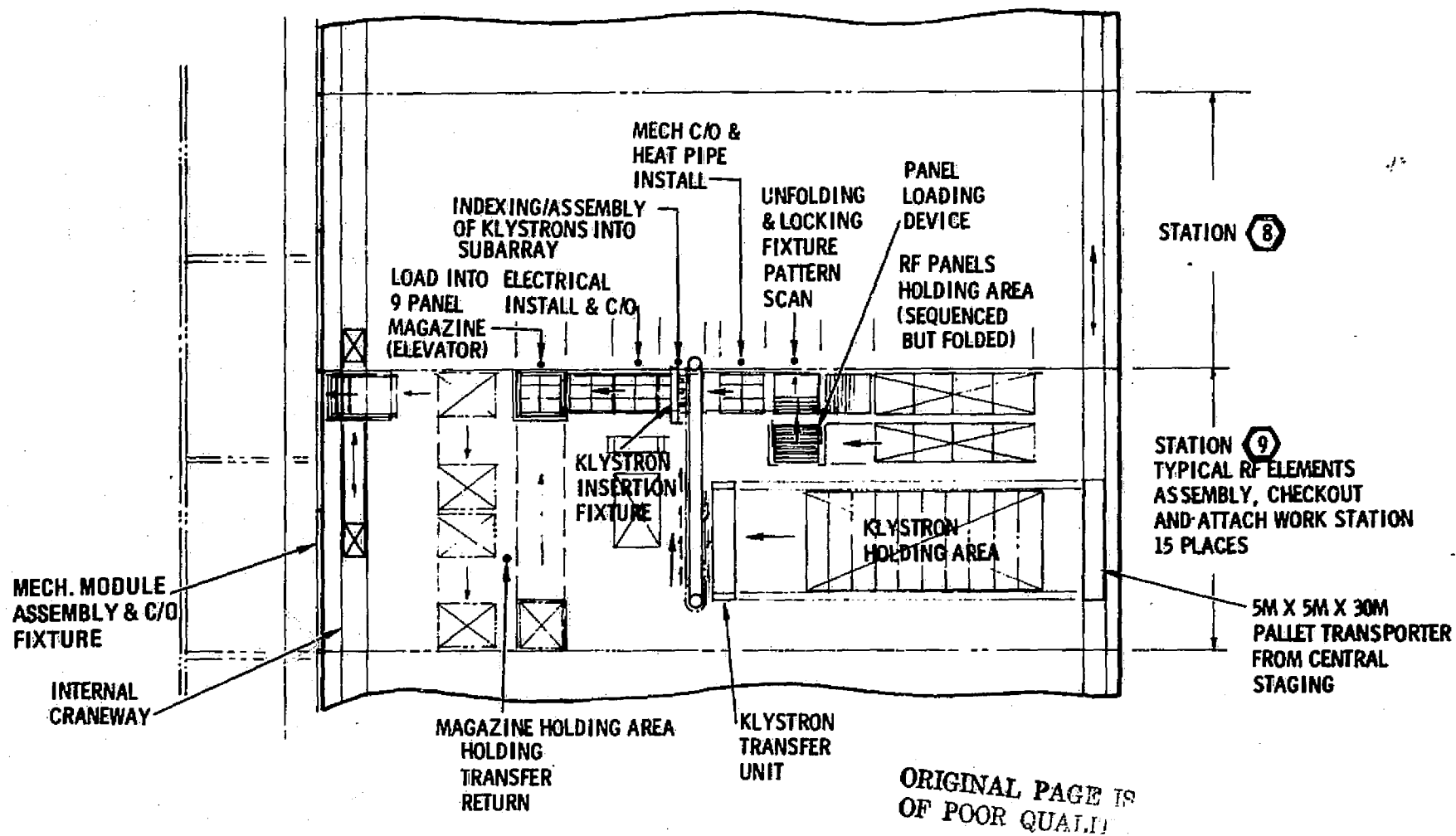
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PLAN VIEW, SUBARRAY ASSEMBLY STATION

At this station the waveguide subarrays are unfolded to their operational surface dimensions of approximately $11m \times 10m$ and passed through the mechanical checkout station and klystron indexing/assembly station, where the klystrons are automatically installed. The assembly of subarray and klystrons move to the electrical station where the electronic control boxes are installed, electrical connections made, and the assembly functionally checked out. Nine assemblies of identical configurations are loaded into the elevator magazine which transfers them to the mechanical module indexing/assembly crane.

SUBARRAY ASSEMBLY STATION ⑨ PLAN (TYPICAL 15 STATIONS)



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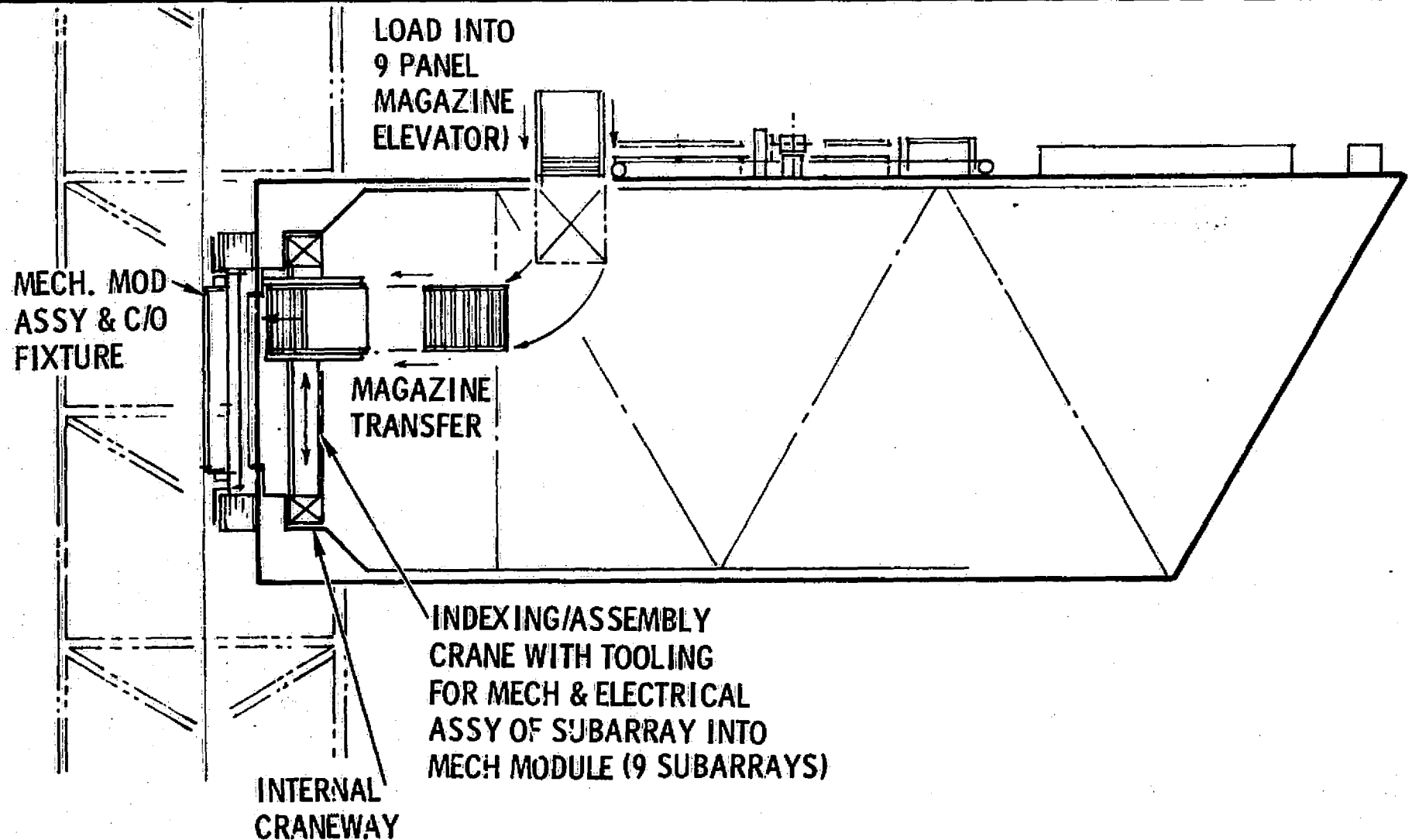
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ELEVATION VIEW SUBARRAY ASSEMBLY STATION

This is an elevation of the previous chart showing the magazine transfer of the assembled subarrays to the index/assembly crane.

SUBARRAY ASSEMBLY STATION ⑨ ELEVATION
(TYPICAL 15 STATIONS)



SATELLITE CONSTRUCTION CREW SHIFT SIZE

● UPPER DECK	4/TROUGH X 3 TROUGHS =	12	CREWMEN/SHIFT
● MIDDLE DECK	4/TROUGH X 3 TROUGHS =	12	
● LOWER DECK	12/TROUGH X 3 TROUGHS =	36	
● REFLECTORS	6/TROUGH X 3 TROUGHS =	18	
● SB/REF. TRANSPORTERS	2/TRANSPORTER X 3 TRANSPORTERS =	6	
● TRIBEAM FABRICATOR		10	
CONTINGENCY CREW			
● DM&C CENTER		7	
● CONSTRUCTION OPS CONTROL CENTER		8	
● ANTENNA CONSTRUCTION		99	
TOTAL		206	CONSTRUCTION CREWMAN/SHIFT



KEY ISSUES

- ACCESSIBILITY AND MAINTENANCE
- 50 M TRIBEAM JOINTS
- CONTINGENCY OPERATIONS
 - REWORK/RESCHEDULING
 - LOGISTICS INTERRUPTIONS
- CREW/MACHINE CAPABILITIES VS REQUIREMENTS
 - PRECISE HANDLING OF LARGE MASSES
 - PRECISION INSTALLATION WITH MANIPULATORS
- SCB INTRA-FACILITY TRANSPORTATION



HLLV GROUND RULES/ASSUMPTIONS

The ground rules and assumptions outlined for preliminary HLLV concept definition are consistent with recent COR redirection. The preliminary concept resulting from these ground rules will then be subjected to various trade studies/alternate options analyses.

HLLV GROUND RULES/ASSUMPTIONS

- TWO-STAGE VERTICAL TAKE OFF/HORIZONTAL LANDING (VTO/HL)
- FLY-BACK CAPABILITY BOTH STAGES - ABES FIRST STAGE ONLY
- PARALLEL BURN WITH PROPELLANT CROSSFEED
- LOX/RP FIRST STAGE - LOX/LH₂ SECOND STAGE
- HIGH P_c ENGINES - SECOND STAGE DUAL MODE
- "OPTIMUM" STAGING VELOCITY AND ALTITUDE
- CIRCA 1985 TECHNOLOGY BASE - 16% WEIGHT REDUCTION⁽¹⁾/LRC I_s VALUES⁽²⁾
- ORBITAL PARAMETERS - 500 KM @ 28.5° INCLINATION
- PAYLOAD CAPABILITY - 225 x 10³ KG UP/45 x 10³ KG DOWN
- THRUST-TO-WEIGHT - 1.35 LIFTOFF/3.0 MAX
- 10% WEIGHT GROWTH ALLOWANCE - 2% DELTA V MARGIN (SECOND STAGE)

(1) NASA CR-2867 OCT. 1977

(2) FSTSA REFERENCE DATA DEC. 1976



HLLV TRADE STUDIES

The preliminary HLLV concept will be modified to assess the effect on configuration, cost, etc., resulting from the deletion of propellant cross-feed and the parallel burn mode.

An alternate booster engine using tri-propellants will be evaluated. The LOX/RP engine turbopumps will be LOX/LH₂ driven and the engine will be LH₂ cooled. The relative merits of a "heat sink" booster and liftoff thrust-to-weight sensitivity will be evaluated.

HLLV TRADE STUDIES

- EVALUATE WITHOUT PROPELLANT CROSSFEED
- EVALUATE WITHOUT PARALLEL BURN
- TRI-PROPELLANT OPERATION - LOX/RP/LH₂ (COOLING)
- 2000 m/sec STAGING VELOCITY (HEAT SINK BOOSTER)
- LIFTOFF THRUST-TO-WEIGHT SENSITIVITY



HLLV STUDY APPROACH AND STATUS

An existing vehicle scaling program, a modified STS scaling program, will be used for vehicle synthesis. The LRC POST Program will be used for trajectory and staging optimization. An early STS "Fly-Back" booster concept will be used as a starting point in establishing scaling parameters. The computer program will be ready for use within the next week. The data contained in this presentation were prepared using manual calculating methods.

HLLV STUDY APPROACH AND STATUS

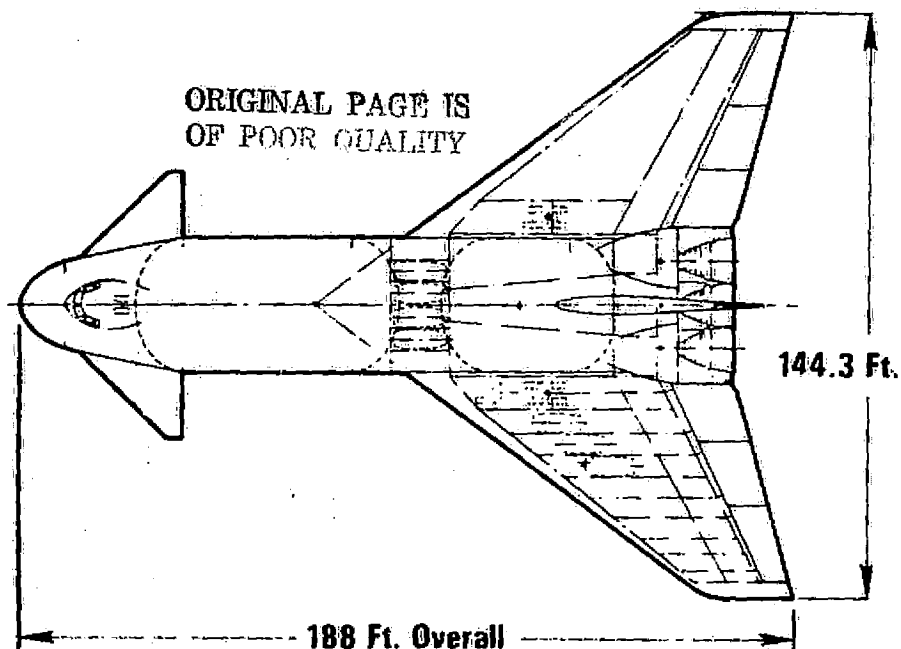
- MODIFIED STS GENERAL SIZING PROGRAM
- STS "FLY-BACK" BOOSTER STUDIES - DATA BASE
- ESTABLISH PRELIMINARY CONFIGURATION - PERFORM TRADES
- PREPARE CANDIDATE VEHICLE CONCEPTUAL LAYOUTS
- COMPUTER PROGRAM READY 6/26/78
- PRELIMINARY SIZING DATA - MANUAL CALCULATIONS



HLLV SCALING BASELINE

The baseline configuration/characteristics to be used for scaling is an early STS fly-back booster concept. This vehicle was selected because of the extensive analysis, including wind tunnel testing, which were performed during the STS Phase "B" studies. Suitable technology advancement criteria will be applied.

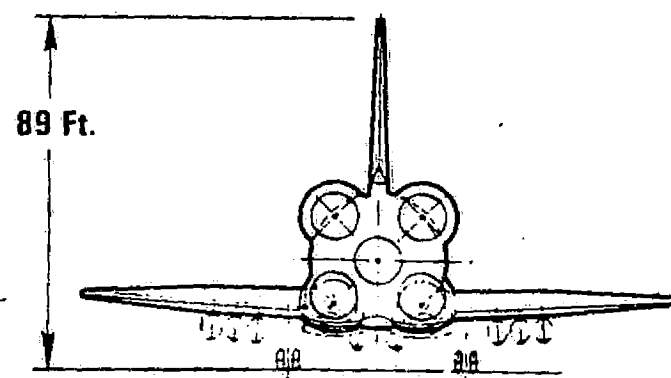
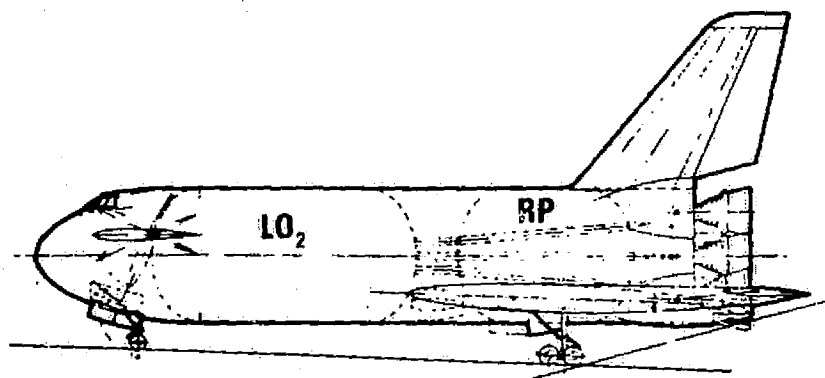
HLLV SCALING BASELINE



• Blow	4.318 M Lb.
• Entry Wt.	726 K Lb.
• Landing Wt.	628 K Lb.

• Flyback Dist	182 N.Mi.
• JP-5 Fuel	55.6 K Lb.
• Staging Vel	6,000 FPS

• Wing Area (Theo.)	8,549 Ft ²
• V.T. Area	1,300 Ft ²
• Canard Area	485 Ft ²



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HLLV SCALING BASELINE

The scaling baseline shows a usable propellant to BLOW mass ratio of 0.83. Assuming a 16% improvement in aerothermal structures and systems weights due to technology advancement a practical upper limit in that mass ratio would appear to be 0.87.

HLLV SCALING BASELINE

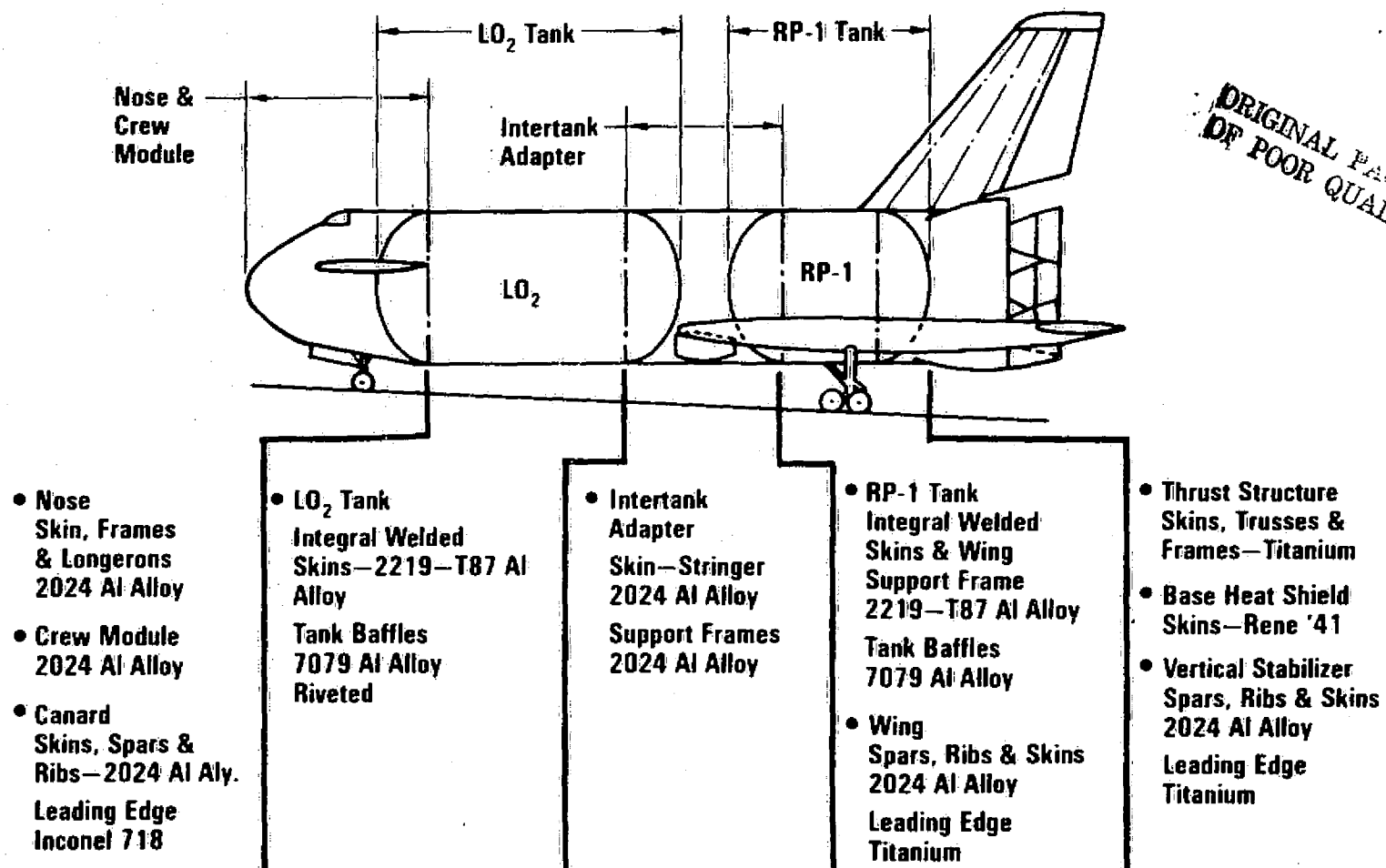
Aerodynamic Surfaces	101,795
Propellant Tanks	63,561
Other Body Structure	149,436
Landing & Recovery	24,571
Propulsion, Ascent	134,087
Propulsion, Cruise & Auxiliary	48,668
Subsystems	30,840
Contingency	43,294
Total Dry Weight	596,252
Residuals & Crew	21,059
In-Flight Losses	65,156
Ascent Propellants	3,578,000
Cruise & Aux. Propellants	57,759
Booster Lift-Off Weight	4,318,226



HLLV HEAT SINK BOOSTER CONFIGURATION

The vast majority of the structure for the heat sink booster is fabricated of aluminum. Titanium and high temperature steel alloys are used only sparingly in local areas of highest temperature.

HLLV HEAT SINK BOOSTER CONFIGURATION



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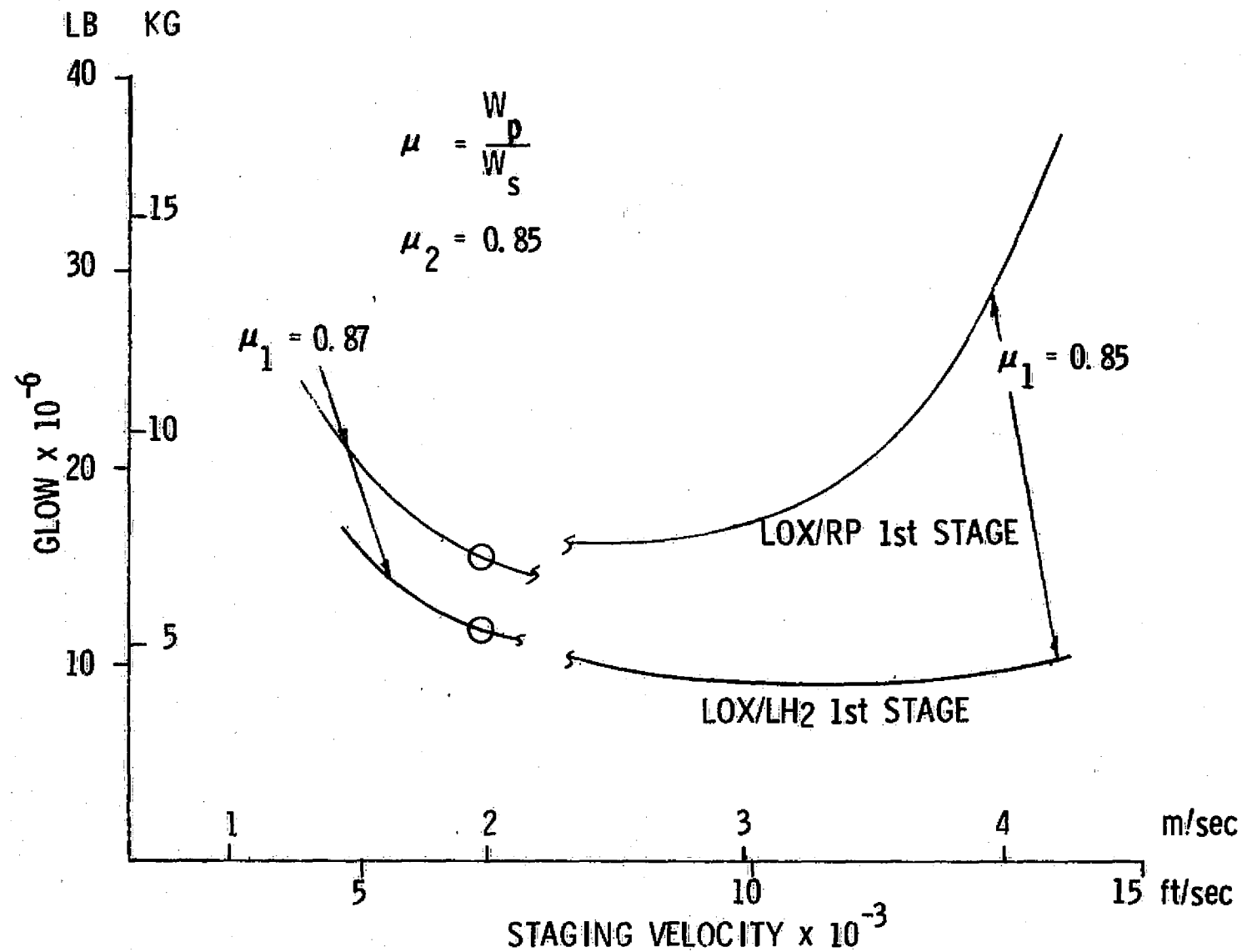
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HLLV GLOW AS A FUNCTION OF STAGING VELOCITY

Data is presented for both a LOX/RP and LOX/LH₂ booster option. The propellant to stage mass fractions were selected on the basis of past studies and potential technology advancement goals. The break shown in the two curves is the result of a transition from an aluminum structure heat sink booster to one requiring considerable high temperature materials or thermal protection system. (A smoother transition would undoubtedly occur in practice, however, the method of calculation did not permit that degree of sophistication.) Minimum GLOW for the LOX/RP booster is in a region where a heat sink booster might well be utilized. The minimum GLOW LOX/LH₂ system, however, has a considerably higher staging velocity requirement, 10,000 to 12,000 ft/sec.

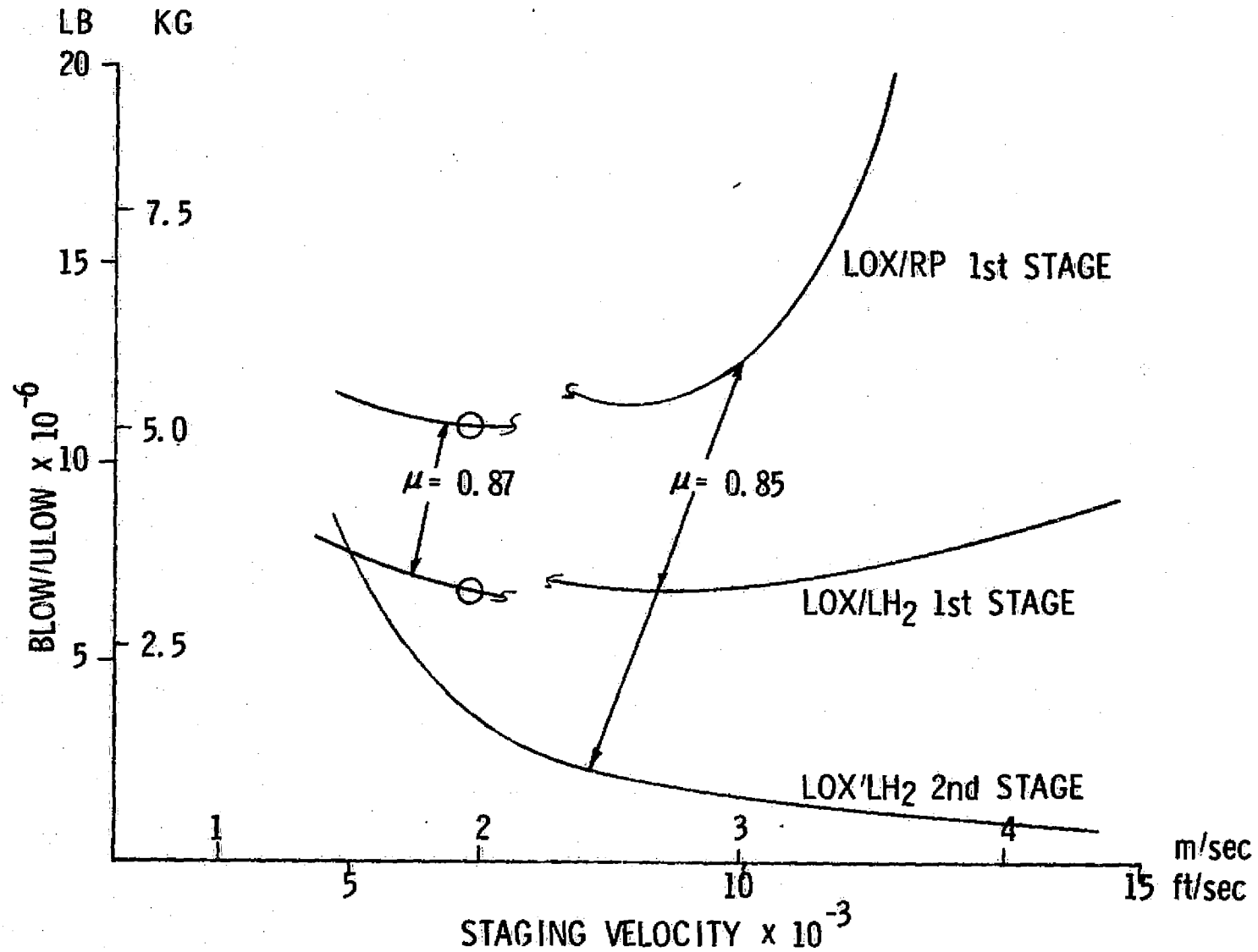
HLLV GLOW AS A FUNCTION OF STAGING VELOCITY



BLOW/ULOW AS A FUNCTION OF STAGING VELOCITY

The relative weight of booster and upper stage elements are presented. It is noted that equal weight does not imply equal size (volume) of the elements. The points indicated are approximate upper limits for "all-aluminum" heat sink booster configurations.

BLOW/ULOW AS A FUNCTION OF STAGING VELOCITY

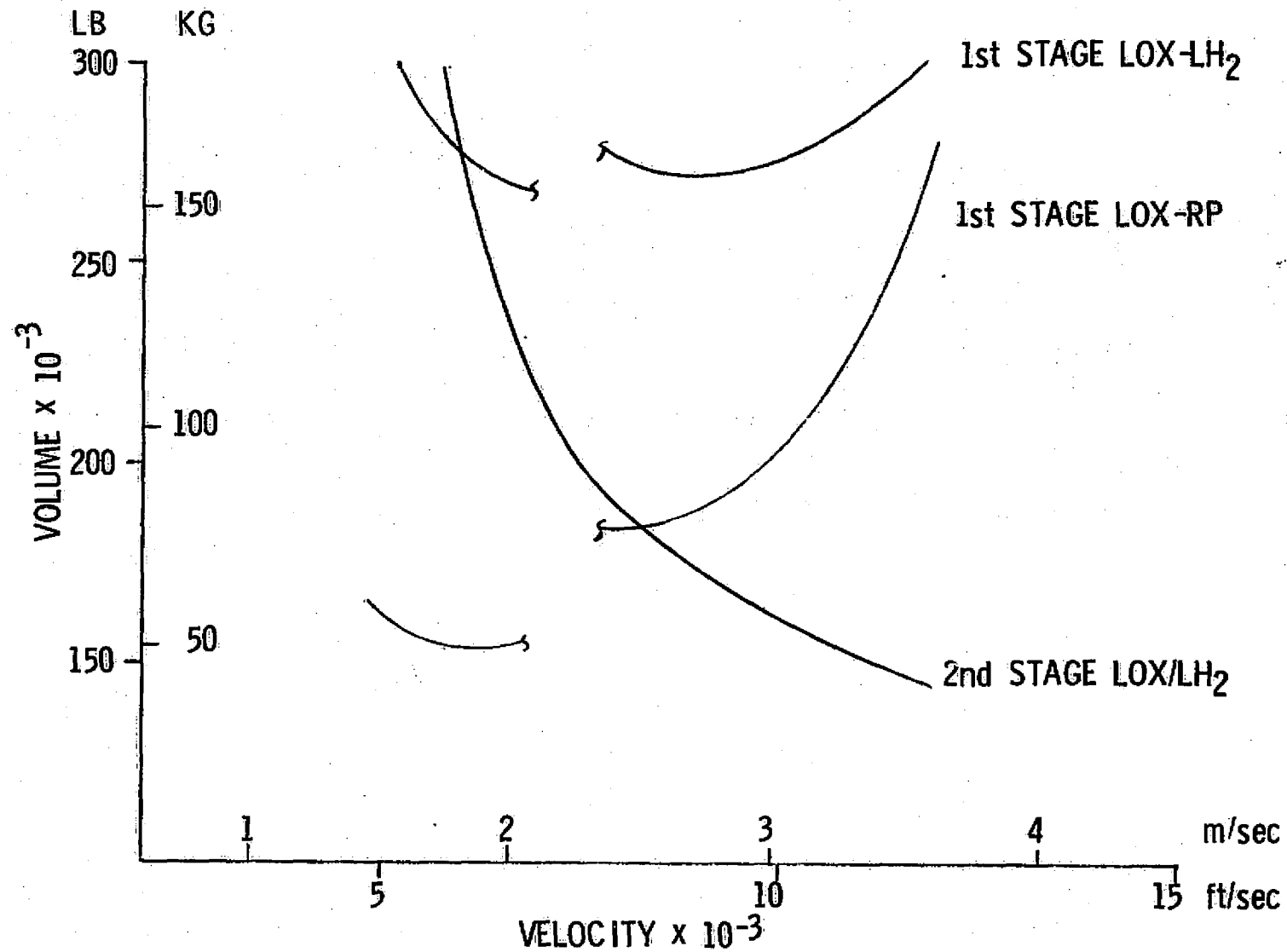


STAGE VOLUME AS A FUNCTION OF STAGING VELOCITY

Stage volume, an indicator of comparable vehicle size, is depicted. An allowance for payload volume in the upper stage was provided. As indicated on the curve, equal size stages for the LOX/RP, LOX/LH₂ system occurs in the area of 8000 ft/sec which is not quite in the region of minimum GLOW and higher velocity than desired for an "all-aluminum" heat-sink booster. A minimum GLOW configuration for the data presented would result in an upper stage larger than the booster.

The all LOX/LH₂ system of comparable size stages does occur within the region of an "all-aluminum" heat-sink booster, however, it is far from being a minimum GLOW configuration.

STAGE VOLUME AS A FUNCTION OF STAGING VELOCITY



SUMMARY AND CONCLUSIONS

A more refined analysis may lead to closer proximity of minimum GLOW/ equal size stages for the LOX/RP configuration booster. The LOX/LH₂ vehicle is considerably lighter but much larger in volume than the LOX/RP system.

Alternate systems to be considered in the study may prove to be promising compromises between vehicle size and weight.

SUMMARY AND CONCLUSIONS

- MINIMUM GLOW LOX/RP BOOSTER - SMALLER THAN 2nd STAGE
- COMMON SIZE STAGES LOX/RP BOOSTER - NEAR MIN GLOW
- LOX/LH₂ 1st STAGE - 50% LIGHTER BUT 50% GREATER VOLUME
- LOX/LH₂ CROSSFEED OR TRI-PROPELLANT OPTION APPEARS PROMISING
- FINAL SELECTION SUBJECT TO OPERATIONS COST ANALYSES



CARGO ORBITAL TRANSFER VEHICLE

COTV studies have been directed toward electric OTV optimization. One of the key areas in these trade studies are thruster module related. (Trip-time trade studies are reported elsewhere in this presentation.) Thruster module synthesis and design is being closely coordinated with NASA/LeRC, who are most current in this technology area. The primary areas of investigation have centered about much larger thrusters operating at higher power levels in order to reduce the number of thrusters required and consequently on-orbit operational requirements.

CARGO ORBITAL TRANSFER VEHICLE

- SPECIFIC IMPULSE, THRUST, TRIP TIME, ETC., TRADE STUDIES

- COORDINATION WITH LeRC

- LARGE DIAMETER THRUSTERS

FEWER THRUSTERS

HIGHER EFFICIENCY

BETTER HEAT REJECTION

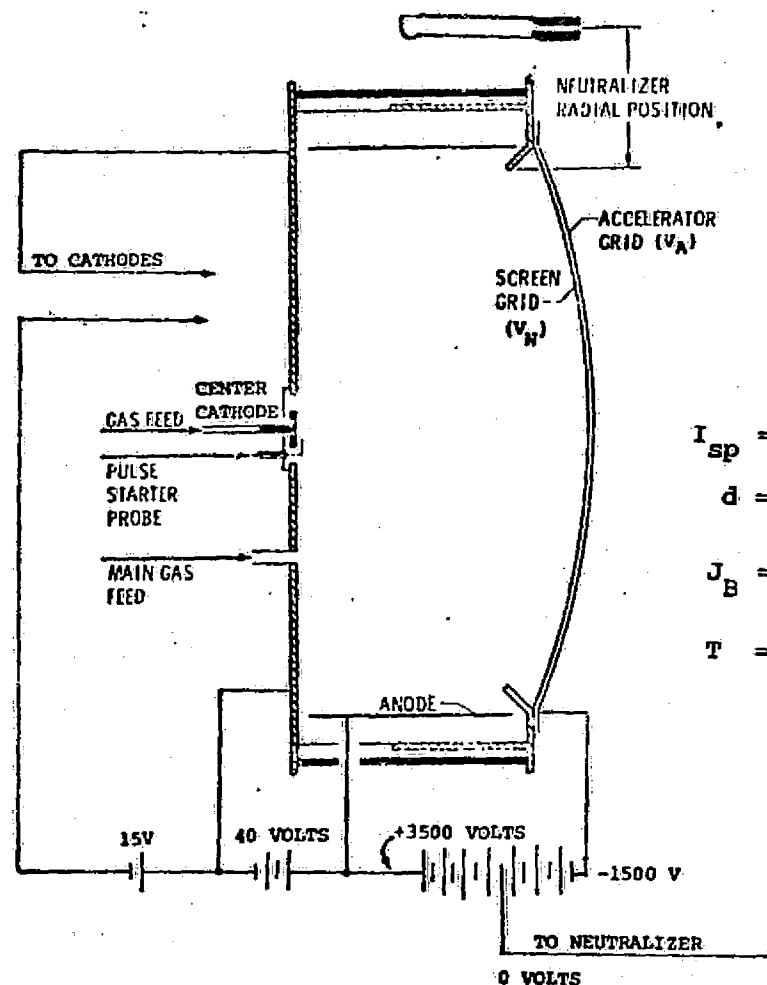


ARGON ION THRUSTER MODULE

Typical performance parameters of a candidate thruster configuration are presented. The elements of an argon ion thruster are identified and typical voltage requirements noted.

The ratio of grid set voltage and span gap are key elements in the design of thruster.

ARGON ION THRUSTER MODULE



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$$I_{sp} = 10,875$$

$$d = 83.0 \text{ cm}$$

$$J_B = 719.77 \text{ A}$$

$$T = 34.86 \text{ N}$$



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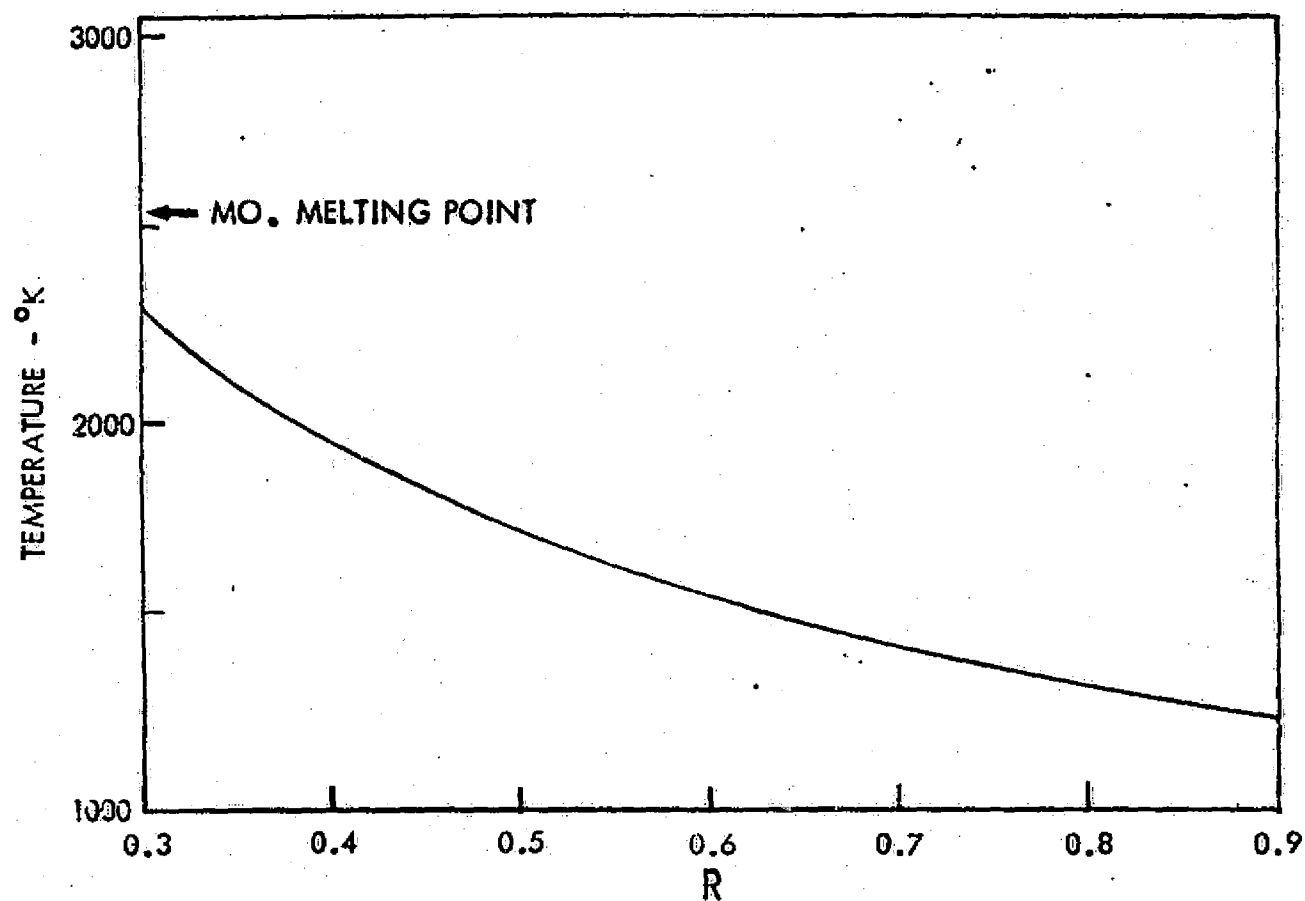
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GRID SET TEMPERATURE AS A FUNCTION OF VOLTAGE RATIO

Grid set temperature as a function of accelerating voltage to anode voltage is depicted. The melting point of molybdenum (a candidate grid material) is indicated. Considerable data has shown that molybdenum is capable of continued operation at temperatures up to 1900°K without adverse material effects. This would then yield an allowable voltage ratio of approximately 0.4.

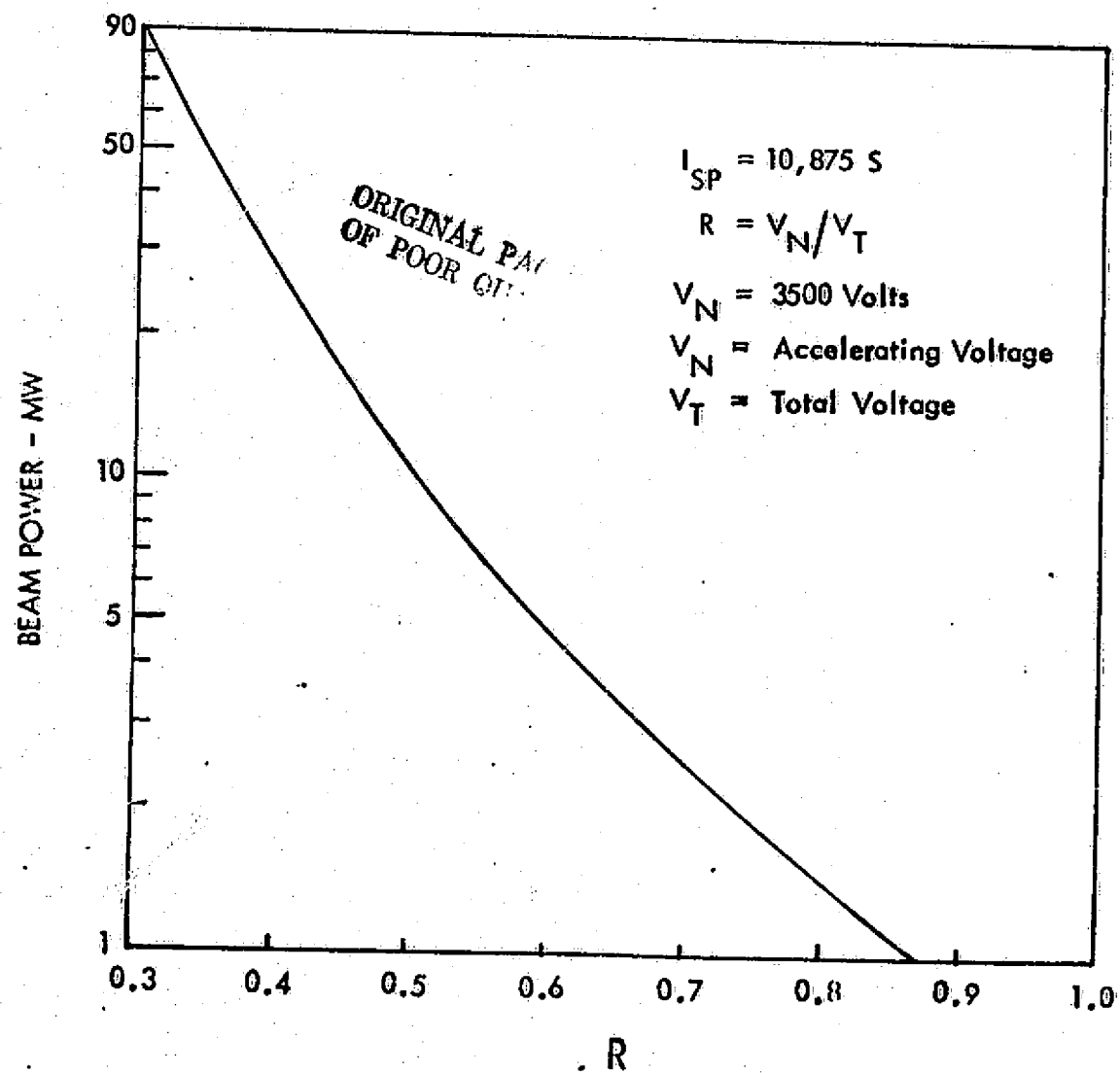
GRID SET TEMPERATURE AS A FUNCTION OF VOLTAGE RATIO



THRUSTER BEAM POWER AS A FUNCTION OF VOLTAGE RATIO

Using the upper limit operating temperature for a molybdenum grid indicated on the previous chart ($R = 0.4$), a beam power level of approximately 32 mW per thruster would be permissible.

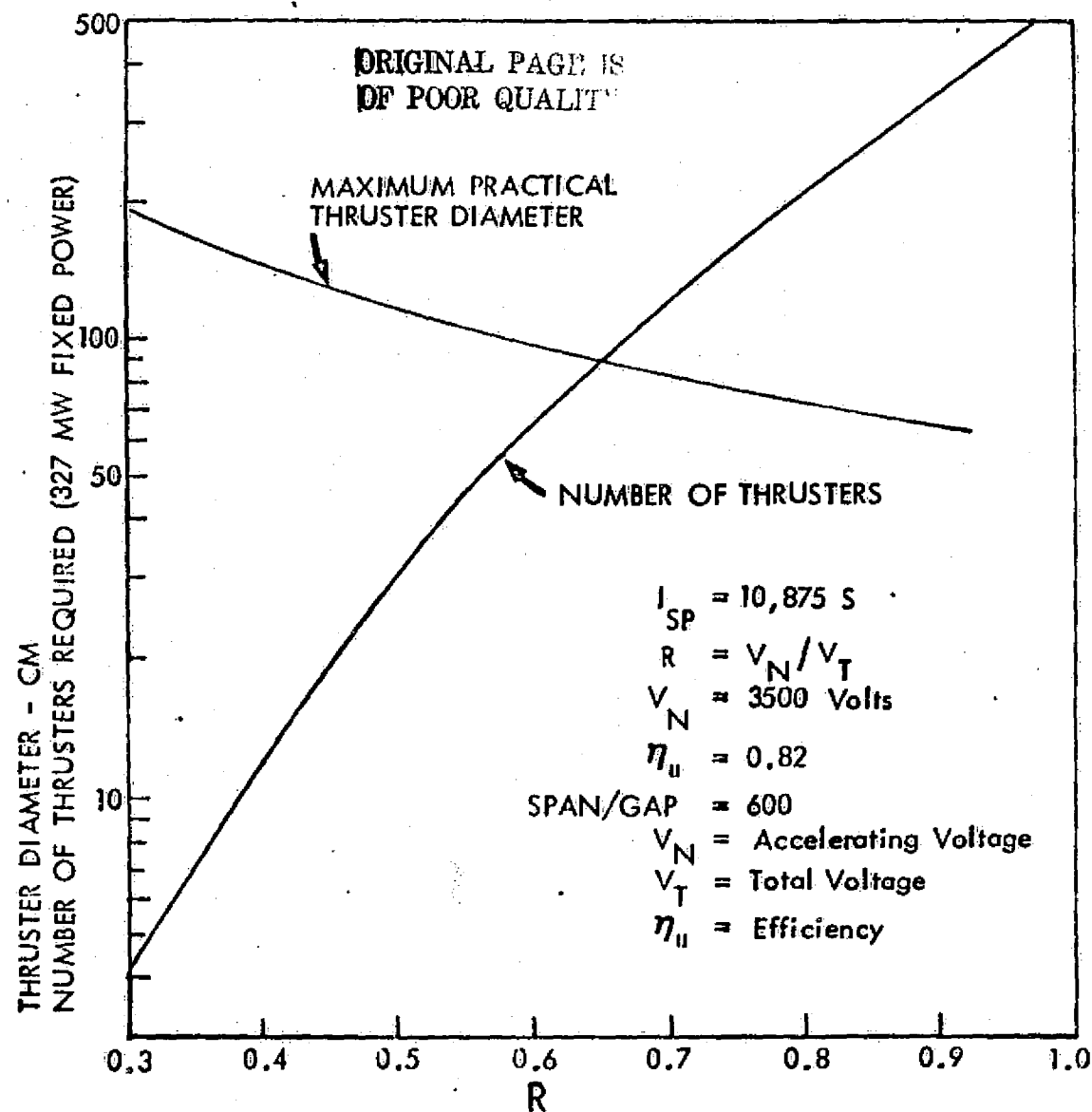
THRUSTER BEAM POWER AS A FUNCTION OF VOLTAGE RATIO



THRUSTER DIAMETER AND NUMBER OF THRUSTERS
AS A FUNCTION OF VOLTAGE RATIO

The maximum practical diameter thruster is based upon the maximum span/gap ratio of 600, a limit imposed to preclude arcing or voltage breakdown between grid sets. Again referring to the allowable voltage ratio (temperature limit of Mo) a maximum thruster diameter of approximately 140 cm is permissible. Based upon the Rockwell "baseline" COTV configuration developed under our previous contract, this would reduce the number of thrusters required from 270 to about 12, which is even more significant when the requirement for installation and refurbishment of thrusters on-orbit are considered.

THRUSTER DIAMETER AND NUMBER OF THRUSTERS AS A FUNCTION OF VOLTAGE RATIO



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SUMMARY AND STATUS

The reduction in the number of thrusters and the attendant reduction in operations requirements and cost are self-evident. The data presented was for a single value of I_s (10,875 s); variation of this parameter along with weight and cost is yet to be accomplished. Also, the results of this analysis will be used to iterate the trip-time optimization analyses.

SUMMARY AND STATUS

- SIGNIFICANT REDUCTION IN NUMBER OF THRUSTERS POSSIBLE
- REDUCED REFURBISHMENT TIME/COMPLEXITY/COST
- THRUSTER I_s AND COST TRADES TO BE COMPLETED
- INCORPORATE REVISED DATA IN TRIP-TIME ANALYSES



SPS RESEARCH AND DEVELOPMENT PLANNING REASSESSMENT

The probable inclusion of an extended Exploratory Research Program in SPS Development Planning, to evaluate microwave technical feasibility and environmental impact, needs to be evaluated at this point in time for its probable effect on overall development/verification planning options and time-lines.

The objectives of this reassessment are to synthesize all of the SPS projected research/development plans to date, including NASA 5 year plan multi-application enabling technology that will provide development support for the SPS system.

An underlying premise is that a heavily-funded dedicated SPS development effort in the next 5 years or so appears increasingly improbable. This leads to a planning logic that builds upon on-going and planned ground and space test activities that can result in SPS developmental progress if they can be appropriately torqued to achieve significant advancement of SPS technology, while also providing other planned benefits.

SPS RESEARCH AND DEVELOPMENT PLANNING NETWORK

OBJECTIVES

- ✓ ESTABLISH RELATIONSHIP OF EXPLORATORY RESEARCH PLAN TO OVERALL SPS VERIFICATION PLAN
- ✓ CATEGORIZE NASA AND DOE FUNDING AREAS
- ✓ SYNTHESIZE MSFC/JSC SPS PLANNING OPTIONS
- ✓ INTEGRATE
 - DOE ENVIRONMENTAL STUDIES
 - NASA LSS 5-YEAR PLANNING
 - SPS DEVELOPMENT PLANNING
- ✓ ESTABLISH MAJOR PLANNING MILESTONES FOR GROUND & SPACE TEST ACTIVITIES DEFINITION
- ✓ IDENTIFY & HIGHLIGHT SPS PLANNING ANOMALIES (I.E., LEO-LEO MW TEST VS. GRD-GEO MW TEST)



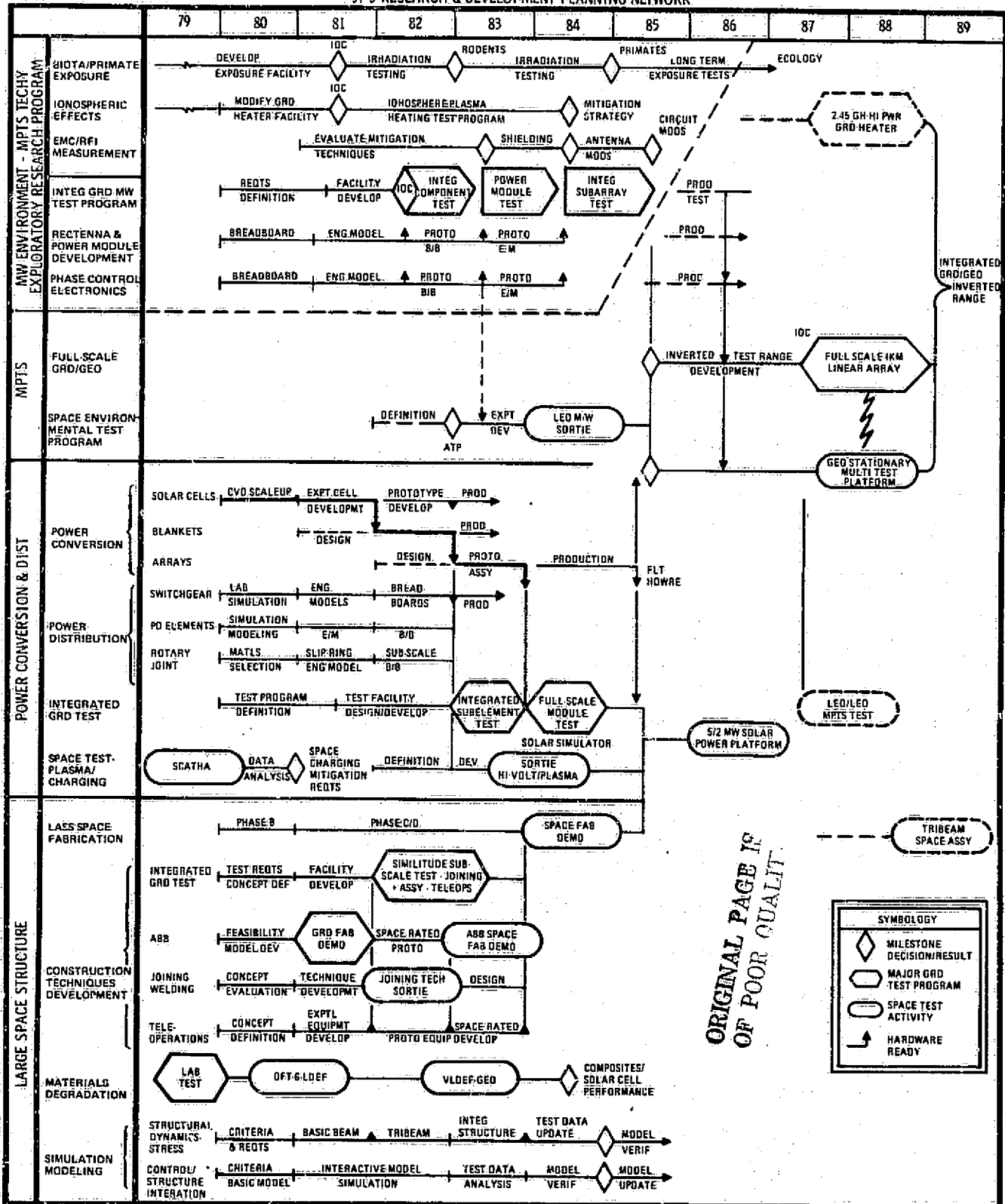
SPS RESEARCH AND DEVELOPMENT NETWORK

A preliminary synthesis of the projected SPS development network is shown. The exploratory research plan segment is contained within the dashed lines and provides the "seed-bed" for prototype MPTS development.

Planned and on-going NASA enabling technology for power conversion/distribution and large space structures development are structured to provide evolutionary timelines leading to large SPS-type subscale space test articles during the end of the decade.

The commitment to large-scale SPS development ground and space test activity will come about 1985 based upon Exploratory Research Program results and will require funding levels on the order of several billions of dollars.

SPS RESEARCH & DEVELOPMENT PLANNING NETWORK



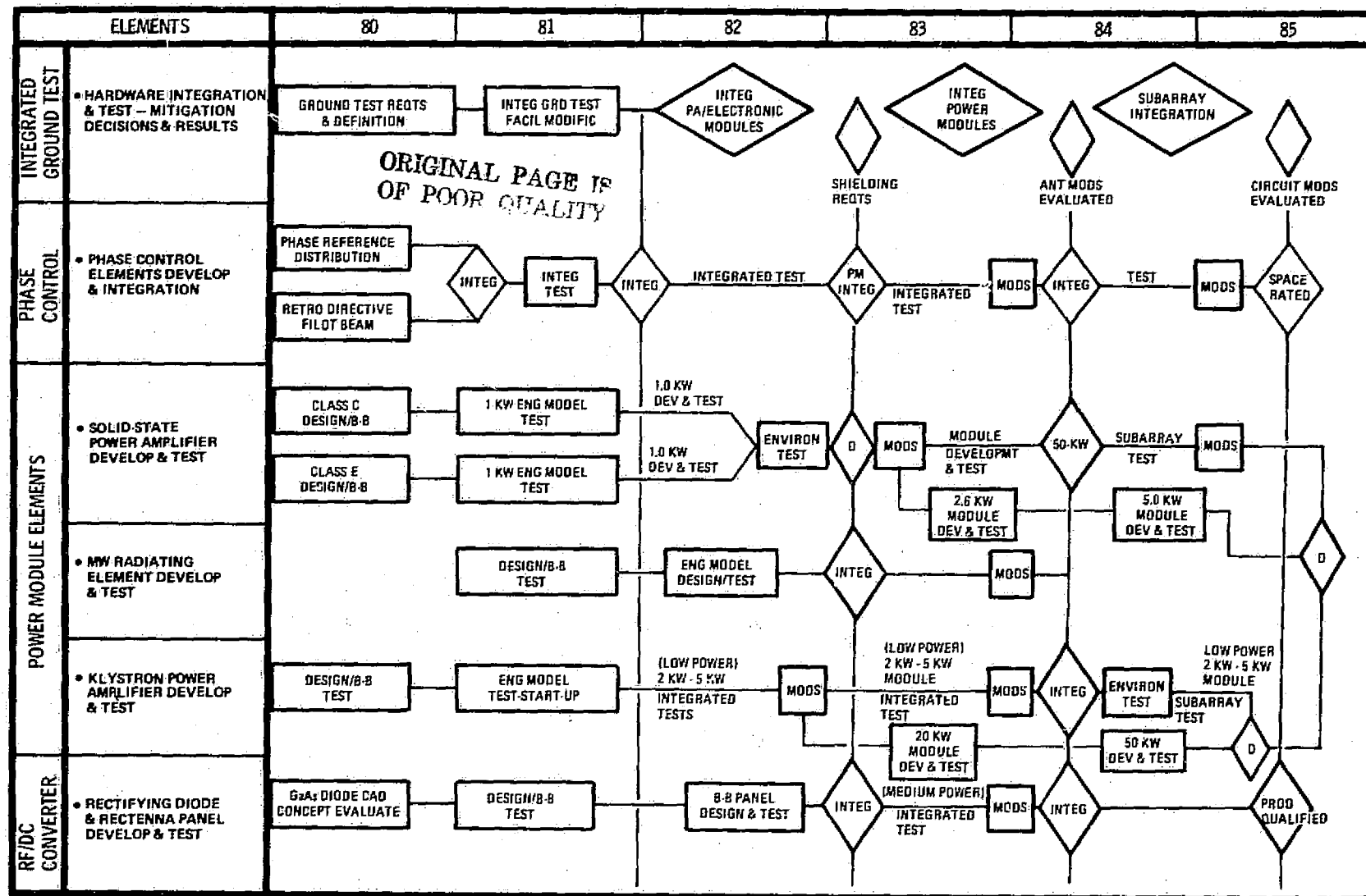
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MICROWAVE EXPLORATORY RESEARCH NETWORK

A generalized research network summarizing the microwave measurements segment of the proposed Exploratory Research Program is shown. The microwave exploratory research effort should involve a parallel study of the two primary power module candidate devices; the klystron and the solid state transistor. Both types of modules can be tested in the same facility. The main differences in the two candidates' test facilities will be the power supply set-up, X-ray testing for the klystron and magnetic field susceptibility testing for the klystron.

The phase control subsystem network implies the development of a single baseline circuit although it would be more desirable to carry two competing phase control schemes through the exploratory research phase as well. The presently recommended funding levels for the overall research program will not be adequate for development of competing power-amplifier and phase control elements.

STRAWMAN MW EXPLORATORY RESEARCH NETWORK



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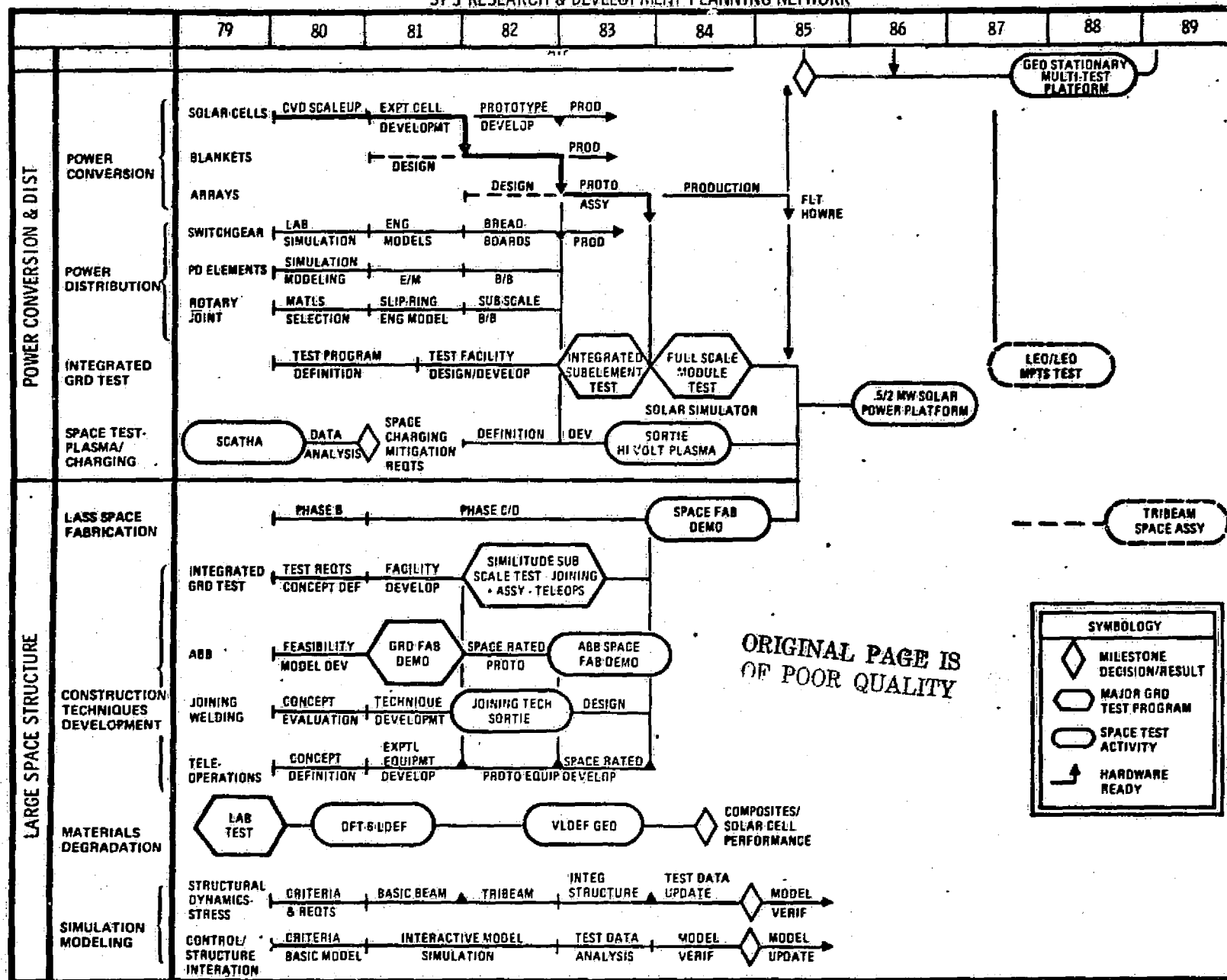
POWER CONVERSION/DISTRIBUTION AND LARGE STRUCTURES PLANNING TIMELINES

Developmental support for SPS power conversion and distribution consists of DOE solar cell production research and NASA solar array development and high-voltage/plasma research. A concentrated program for GaAs solar cell development needs to be pursued. Power distribution development effort mainly involves conventional satellite low-power subsystem elements and requires more effort in the 20 kV to 40 kV high-voltage components such as switchgear and dc/dc converters, as well as rotary joints. High voltage/plasma interactions need to be evaluated through Shuttle sorties to establish LEO power system thresholds.

The development of large space structure technology is essentially a NASA supported effort at present with the emphasis on generic development with broad application. SPS requirements reflect the ultimate limiting condition and should be reflected back into basic technology development to enhance commonality and applicability to very large SPS subscale test articles projected for the late 80's.

Composite materials degradation in the space environment is a subject for early intensive evaluation both in ground chambers and the in-situ environment. Economical early access to the geosynchronous environment for basic materials evaluation and major systems testing is a driving requirement.

SPS RESEARCH & DEVELOPMENT PLANNING NETWORK

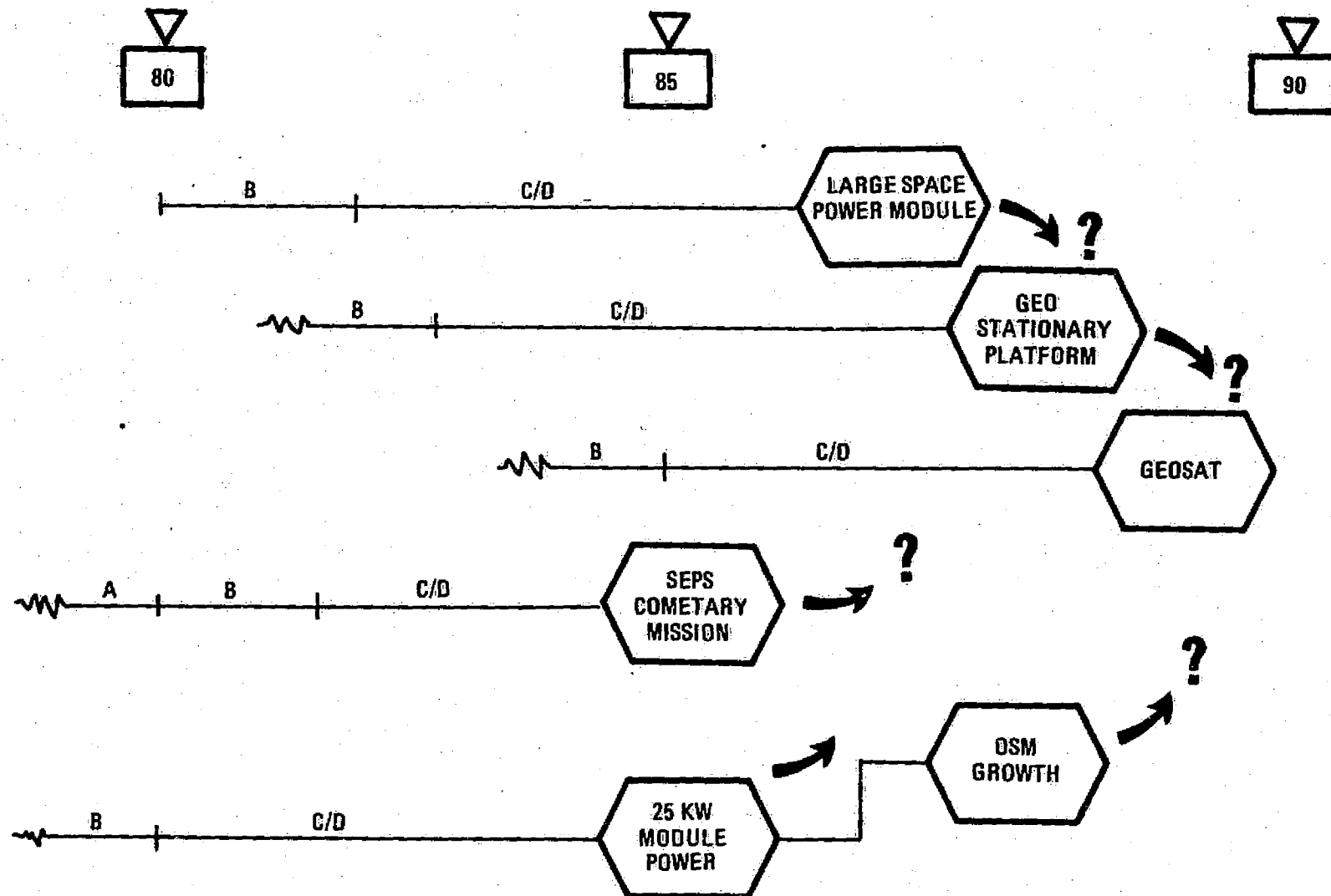


HOW WILL THE SPS GEOSAT TEST PLATFORM EVOLVE?

An essential requirement exists for major SPS subsystem test and evaluation at geosynchronous altitude late in the 80's. This SPS multi-test platform will operate in conjunction with a full-scale MPTS linear array on the ground functioning as an inverted microwave test range. It will also provide extensive component and integrated subsystem test evaluation in the geosynchronous environment. The mission requirement for the SPS geostationary test system is in competition with several other planned large space structure mission developments during the mid and late 80's. Practical aspects of lead-time and total available funding would appear to preclude parallel dedicated development of all of the proposed systems.

It appears likely that SPS geosynchronous test requirements and test system definition will have to be satisfied through the evolutionary utilization of NASA large structure space projects that evolve and are funded. Requirements for multi-mission applicability, construction modularity, and a broad range of power, size, and mass options which include SPS test verification objectives will need to be evaluated and synthesized.

HOW WILL THE SPS GEOSAT TEST PLATFORM EVOLVE?



SPS DEVELOPMENT PLANNING ISSUES

SPS development planning will continue to evolve and will be significantly impacted by the major programmatic and system concept definition issues summarized on the facing chart.

Programmatic issues relate to ultimate planning decisions on exploratory research effort, results of early low-power ionospheric testing, and evolving NASA space planning for large structure geosynchronous missions and satellite systems.

Specific SPS subsystem test planning will evolve with configuration - dependent system decisions on phase control, power amplifiers, solar cells, and basic structural beam element sizing.

SPS DEVELOPMENT PLANNING ISSUES

● PROGRAMMATIC

- ULTIMATE SCOPE AND FUNDING LEVEL FOR EXPLORATORY RESEARCH PROGRAM
- DEGREE OF SUCCESS OF IONOSPHERE HEATING EFFECTS SCALING ANALYSIS
- POTENTIAL FOR HYBRID-TYPE MAJOR SPS SUB-SCALE SPACE TEST ARTICLES - ACCESS TO GEO ENVIRONMENT

● CONFIGURATION - DEPENDENT

- PHASE CONTROL TECHNIQUE SELECTION
- POWER AMPLIFIER SELECTION - KLYSTRON VS SOLID-STATE
- SOLAR CELL SELECTION - GaAs VS AMORPHOUS SILICON
- STRUCTURAL ELEMENT SIZING - BASIC BEAM ELEMENT (ABB)
- TRIBEAM



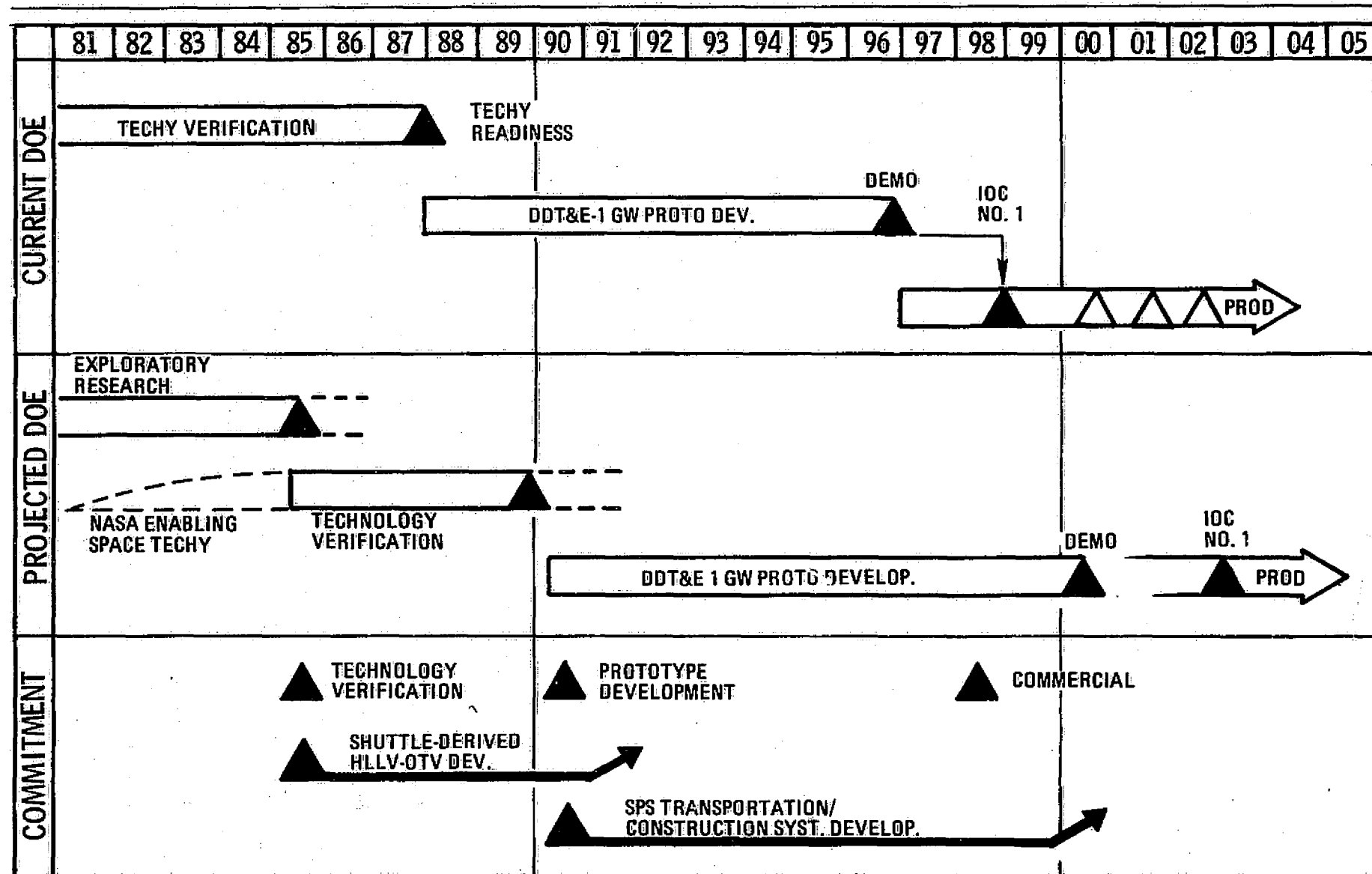
PROJECTED SPS DEVELOPMENT PLAN TIME-LINE

Planned insertion of significant exploratory research effort relating to microwave technical feasibility and environmental impact, into the SPS developmental cycle will ultimately lead to an extension of currently planned production system IOC.

A current projection of SPS development plan phasing is shown on the facing chart. Proposed modified commitment decision milestones are summarized below:

- 1980 ✓ Initiate Exploratory Research Program
- 1985 ✓ Initiate SPS Technology Verification Phase
 ✓ Initiate Shuttle-derived HLLV-OTV Development
- 1990 ✓ Technology State-of-the-Art Cutoff
 ✓ Initiate Prototype System Development
 ✓ Initiate SPS Transportation/Construction Support System Development
- 2000 ✓ 1 GW SPS Prototype Demonstration

PROJECTED SPS DEVELOPMENT PLAN TIME-LINE



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PLANNED FUTURE EFFORT

This chart is self-explanatory.

PLANNED FUTURE EFFORT

- CONTINUED EVALUATION OF BASELINE SYSTEM CONVERGENCE TECHNICAL DECISIONS AND EXPLORATORY RESEARCH BUDGETARY PLANS FOR IMPACT ON DEVELOPMENT PLANNING OPTIONS AND TIMELINES
- FURTHER CONSIDERATION OF HYBRID INTEGRATED SPS SPACE TEST ARTICLES
 - ADVANTAGES AND LIMITATIONS
 - CONSTRAINTS AND TECH. ISSUES
 - DEGREE OF KEY ISSUE RESOLUTION
- PRELIMINARY RESTRUCTURING OF OVERALL SPS DEVELOPMENT PLAN ELEMENT CHART



COST AND PROGRAMMATICS

This chart is self-explanatory.

COST AND PROGRAMMATICS

- SPS ECONOMICS UPDATE

 - DDT&E AND TFU COST BREAKDOWN

 - TIME PHASED COSTS (DDT&E AND TFU)

- SUPPORTING COST ANALYSIS

 - SPACE TRANSPORTATION REQUIREMENTS

 - SPACE BASE AND CONSTRUCTION REQUIREMENTS

- SCHEDULE UPDATE



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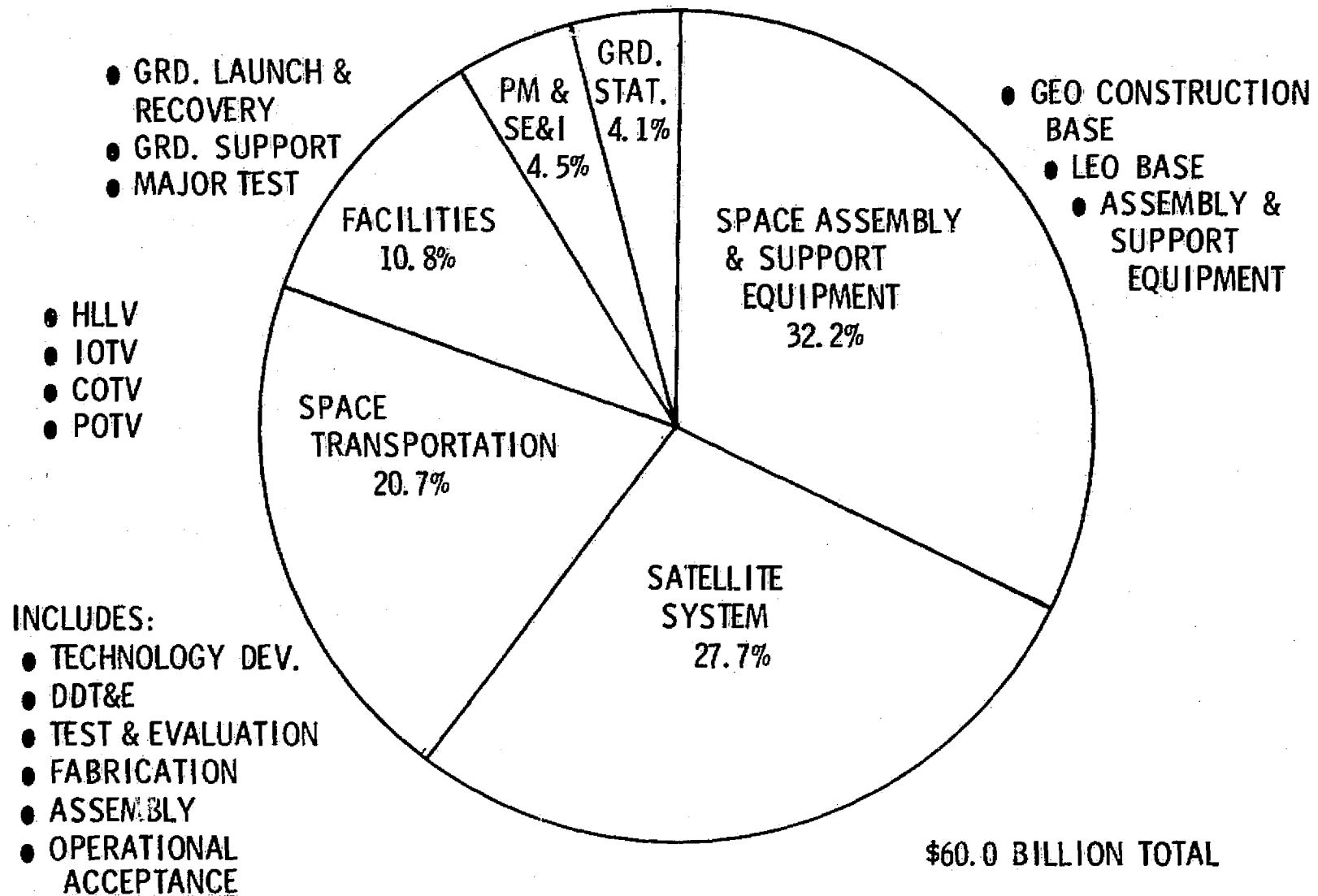
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TOTAL COSTS THROUGH THE FIRST 5 GW OPERATIONAL SPS

This chart shows the percentages of cost distributed in major categories of the SPS program. It covers all DDT&E requirements and the costs to build the first 5 GW operational SPS. The total cost of \$60.0 billion includes costs of a construction base, LEO base, and assembly/support equipment, plus transportation elements and facilities that will be available to build other satellites.

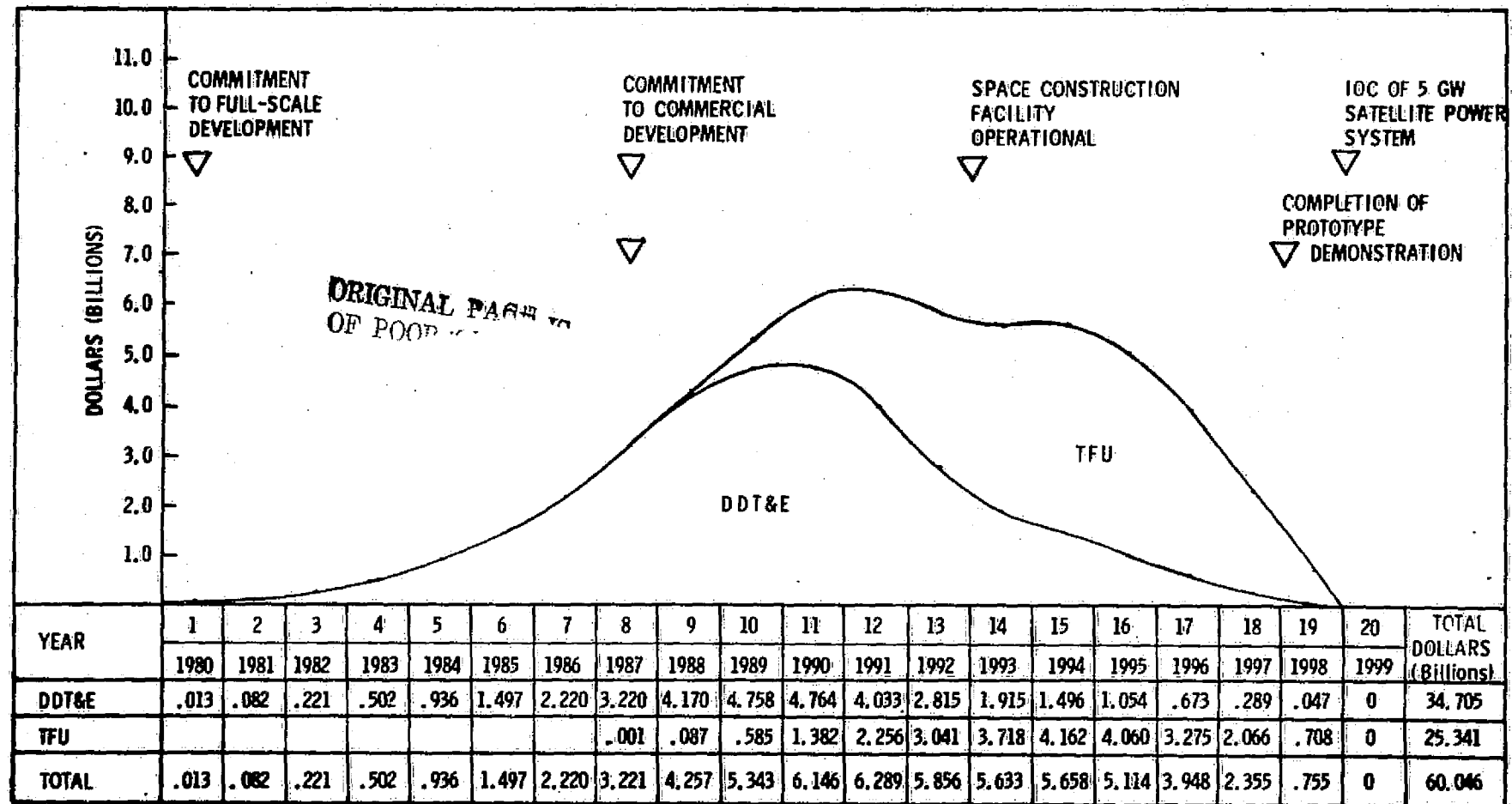
TOTAL COSTS THROUGH THE FIRST 5 GW OPERATIONAL SPS



TIME PHASED COSTS FOR FIRST 5 GW OPERATIONAL SPS

Funding requirements and peak year distributions are shown in this chart for DDT&E and TFU (Theoretical First Unit). DDT&E costs peak at just over \$4.7 billion at 1989-1990. This time period corresponds to the design, development and test activities of SPS elements. TFU costs peak at around \$4.1 billion in 1994-1995, which is the time period associated with construction, assembly, and testing of the systems comprising the satellite.

TIME PHASED COSTS FOR FIRST 5 GW OPERATIONAL SPS



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SPACE TRANSPORTATION ANALYSIS

Requirements and costs for SPS space transportation elements are summarized to identify flights and fleet equivalents needed to 1) build each of the 120 satellites and 2) to operate/maintain each satellite on an annual basis over a 30 year period. Fleet requirements to build the satellite are based on the number of vehicles to complete the satellite fabrication and assembly plus an "equivalent" allowance to maintain the fleet in a fully operational state. This is illustrated in the case of the HLLV - total average fleet investment per satellite - where an equivalent fleet of 2.2 vehicles is needed.

SPACE TRANSPORTATION ANALYSIS

SPACE TRANSPORTATION SYSTEM	ROUND TRIP FLIGHTS			* FLEET REQMTS TO BUILD A SATELLITE	TOTAL AVG FLEET INVEST- MENT PER SATELLITE (DOLLARS, MILLIONS)	FLEET REQMTS FOR OPS/SAT YEAR	FLEET ATTRI- TION (SPARES) REQMTS PER SAT-YR	OPNS COST PER FLIGHT (DOLLARS, MILLIONS)	COST OF OPERATIONS PER SATELLITE YEAR (\$ MILLIONS)	
	LIFE PER VEHICLE	TO BUILD A SATELLITE	TO SUPPORT OPNS (SAT-YR)						FLEET O&M REQMTS*	OPNS & MAINT.
HLLV FLEET	500	500		2.2	611.565					
HLLV OPERATIONS			17.254			.034508	.04141	1.248	21.104	34.162920
IOTV FLEET	500	1000		3.2	2.285					
IOTV OPERATIONS			22.508			.0450	.027	.001	.103	.022508
COTV FLEET	20	11.364		.5667	65.696					
COTV OPERATIONS			.255773			.012789	-	1.420	5.046	.363198
POTV FLEET	300	14.2		.125	1.350					
POTV OPERATIONS			2.0			.006667	.01	.090	.798	.180000
*INCLUDES FLEET ATTRITION/SPARES										

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SPS OPERATIONAL SUPPORT REQUIREMENTS

Major elements of the LEO base, satellite construction base at GEO, and the O&M base on each satellite are identified in this chart. The quantity of modules and assembly/support equipment are total lifetime requirements to build 120 satellite systems over the 30 year period. Only one GEO construction base fixture is needed for the 120 satellite requirement.

SPS OPERATIONAL SUPPORT REQUIREMENTS

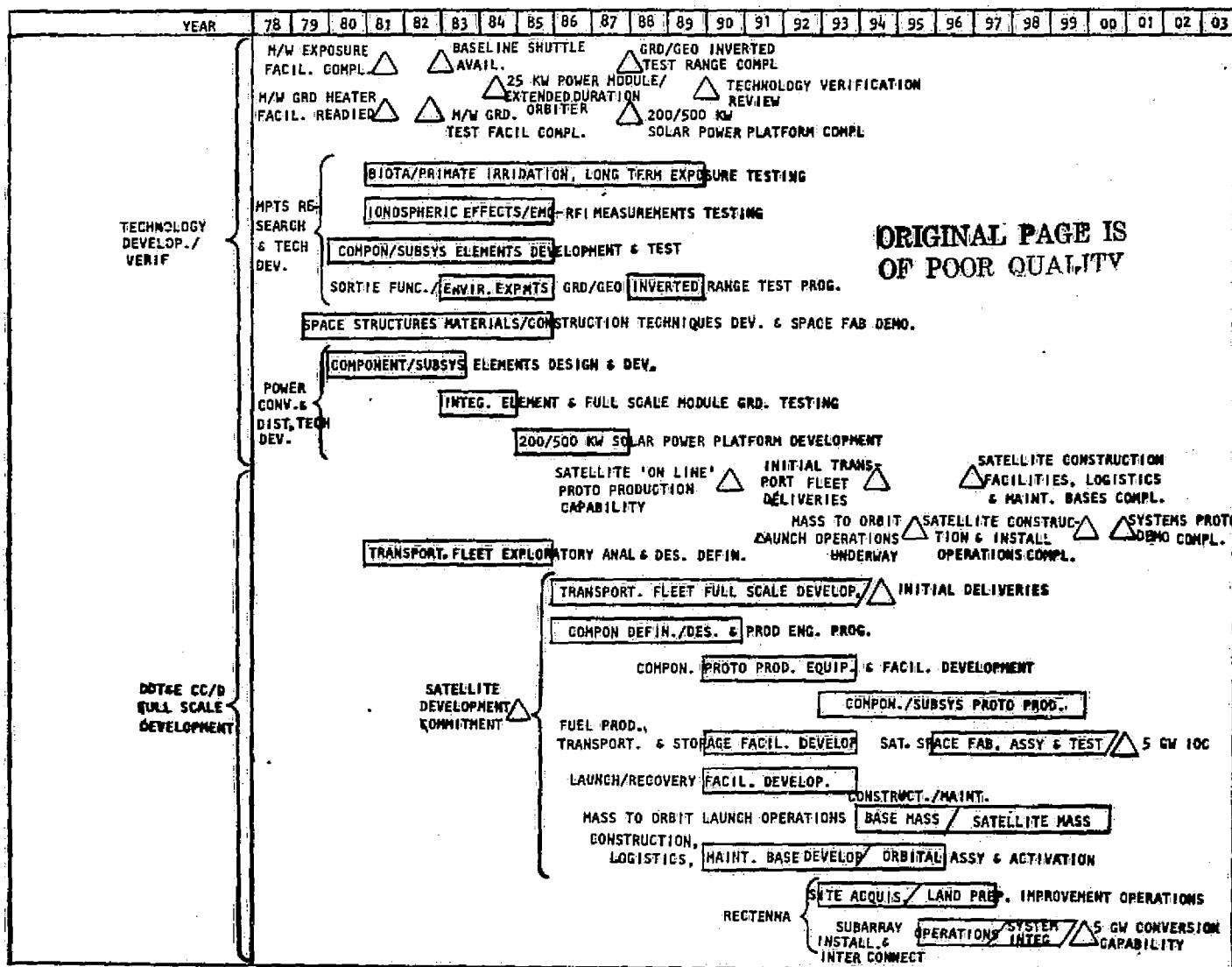
SYSTEM DESCRIPTION	SPS LIFETIME REQUIREMENTS		
	GEO CONSTR BASE	LEO BASE	SAT O&M BASE
CONSTRUCTION BASE FIXTURE	1		
BASE MODULES			
AIRLOCK DOCKING MODULE (ADM)	36		4
CREW HABITABILITY MODULE	28	1	1
CONSUMABLES LOGISTICS MODULE	14		1
BASE MANAGEMENT MODULE	4	1	1
CREW SUPPORT MODULE/EVA		1	1
POWER MODULE	4	1	
PRESSURIZED STORAGE MODULE	4		2
SHIELDING	12		
CREW SUPPORT MODULE	4		
ASSEMBLY AND SUPPORT EQUIPMENT			
BEAM MACHINES	702		
A&SE CASSETTES	7128		
CABLE ATTACHMENT MACHINE	152		
REMOTE MANIPULATOR	108		
SOLAR BLANKET DISPENSER	482		
REFLECTOR (CONCENTRATOR) DISPENSER	36		
CABLE DISPENSER	460		
ANTENNA PANEL INSTALL. EQUIPMENT	3		



SPS SUMMARY PROGRAM PHASES AND MILESTONES

Recent schedule adjustments are shown on this chart as they relate to updates of the technology development/verification activities and sequential phasing of DDT&E/SPS development cycles leading to a 5 GW satellite IOC in the year 2000. This schedule is supported by a Research and Development Planning Network that details the sequences and interrelationships of the (1) MPTS, (2) Power conversion and distribution, and (3) large space structure technology programs.

SPS SUMMARY PROGRAM PHASES AND MILESTONES



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